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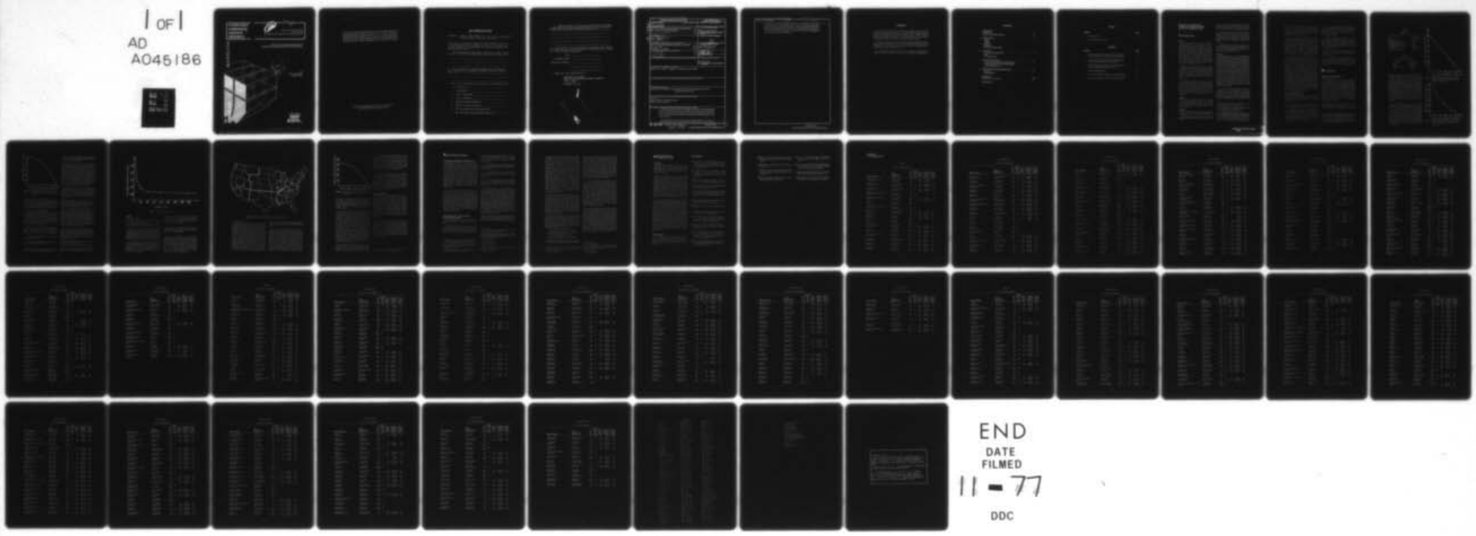

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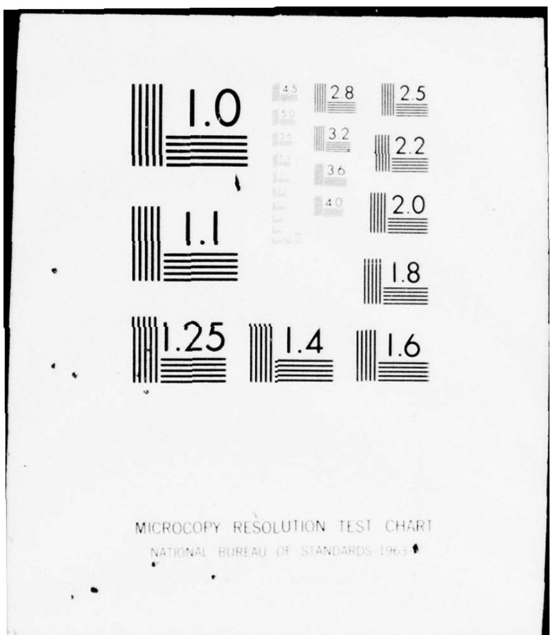
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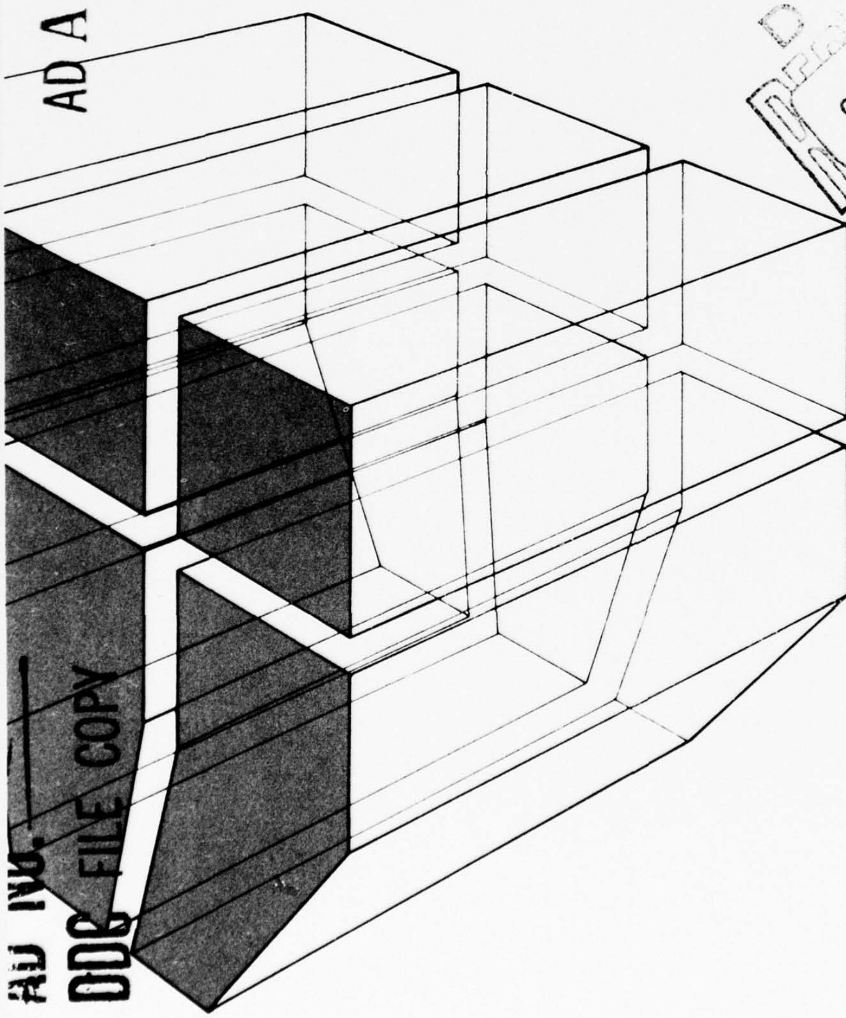
TECHNICAL REPORT M-228
September 1977
Alternatives for Critically Short Construction Materials

USE OF FLY ASH AND HIGH-STRENGTH REINFORCING BARS IN MILITARY CONSTRUCTION

by
Paul A. Howdyshell
David C. Morse



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This report presents the results of an investigation to evaluate fly ash and high-strength reinforcing bars (Grade 60 and above) as alternate construction materials to alleviate the impact of material shortages on military construction. The evaluation was based on the effect of these materials on cost and resource (raw material and energy) intensity of military construction.

The results show that the use of fly ash is economically feasible for 78 percent of all military installations in the United States. The resulting average savings per cubic yard → over

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of concrete would be 73 lb (43 kg/m^3) of cement and 2.72×10^5 Btu (3.75×10^8 J/m^3). This translates into a monetary savings of \$0.87/cu yd (\$1.14/m^3) and an energy savings sufficient to heat the average home in Illinois for 14 hours. Use of Grade 80 and Grade 60 high-strength reinforcing bars in place of the more conventional Grade 40 reinforcing bars can result in maximum material savings of 41 and 25 percent and a corresponding cost savings of 24 and 15 percent, respectively.

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FOREWORD

This investigation was performed for the Directorate of Military Construction, Office of the Chief of Engineers (OCE), under Project 4A762719AT41, "Design, Construction and Operations and Maintenance Technology for Military Facilities"; Task T7, "Materials Research and Development for Military Construction"; Work Unit 005, "Alternatives for Critically Short Construction Materials." The applicable QCR is 1.01.001(4).

This study was conducted by the Construction Materials Branch (MSC) of the Materials and Science Division (MS), U.S. Army Construction Engineering Research Laboratory (CERL). CERL personnel involved in this investigation were Mr. P. A. Howdyshell, Mr. D. C. Morse, Mr. R. E. Muncy, and Mr. R. T. Neu.

Dr. G. R. Williamson is Chief of MS, and Mr. P. A. Howdyshell is Chief of MSC. COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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USE OF FLY ASH AND HIGH-STRENGTH REINFORCING BARS IN MILITARY CONSTRUCTION

1 INTRODUCTION

Problem

Increasing energy and natural resource deficiencies and rising energy costs can be expected to cause increasingly high costs and short supplies of energy- and resource-intensive construction materials. The Corps of Engineers is the world's largest single user of plain and reinforced concrete—the two construction materials used most widely in nonresidential structures. Two of the components of these materials, reinforcing steel and portland cement, are resource- and cost-intensive. Thus, the rising costs and increasingly short supplies of construction materials may have a significant negative effect on military construction.

Alleviating these problems will require (1) increasing productivity with smaller amounts of energy and material resources, and (2) using available construction materials more efficiently. New developments must emphasize efficiency of design and the potential of alternate and perhaps unconventional construction materials.

Two alternate materials with promise for significantly reducing the quantity of cement and reinforcing steel required to perform a given structural function are fly ash and high-strength reinforcing bars (rebars). However, before the advantages of either fly ash or high-strength rebars can be realized, the potential users must be confident of their economy, safety, and acceptability.

Objective

The objective of this investigation was to evaluate fly ash and high-strength rebars for use in military construction based on their effect on the cost and resource (raw materials and energy) intensity of military construction.

Approach

Cost benefit and resource intensity* information concerning the use of fly ash and high-strength rebars in military construction were gathered from fly ash producers and brokers and from the literature. The data for fly ash and rebars were then analyzed separately.

Fly ash data were analyzed for each military installation in the United States. The analysis consisted of optimizing the cost of a fly ash mix of given strength and workability and comparing its cost and energy intensity to those of an equivalent conventional concrete mix.

The high-strength rebar analysis was based on the American Concrete Institute's (ACI) *Building Code Requirements for Reinforced Concrete* (ACI 318-71)[1] and expected material and labor costs.

Background

As previously stated, two of the component materials used to produce plain and reinforced concrete are resource- (energy) and cost-intensive—reinforcing steel and portland cement. The energy consumed in processing reinforcing steel and portland cement is about 43×10^6 Btu/ton (50×10^6 J/kg) and 7.9×10^6 Btu/ton (9.1×10^6 J/kg), respectively.[2] The other material constituents of concrete—sand and gravel—have a relatively small process energy requirement of about 72×10^3 Btu/ton (84×10^3 J/kg).[3] The cost of energy required to produce cement is presently about 25 percent of the total production cost.[4] As the cost of energy goes up (it is expected to increase by four to five times the present amount by the close of the century[5]) and the supply goes down, the costs and availability of energy-intensive construction materials will follow similar trends.

It is thus extremely important that procedures be implemented to reduce the quantity of reinforcing steel and portland cement required to perform a given structural function. Two materials hold considerable promise for achieving this goal: fly ash and high-strength rebars (yield strength greater than or equal to 60 ksi

*Resource intensity is defined as the quantity of resources consumed (both energy and raw material) in producing a given product.

[1] *Building Code Requirements for Reinforced Concrete*, ACI 318-71 (American Concrete Institute, 1971).

[2] A. B. Makhijani and A. N. Lichtenberg, "Energy and Well Being," *Environment*, Vol 14, No. 5 (June 1972).

[3] A. B. Makhijani and A. N. Lichtenberg.

[4] J. E. Funnel and D. Johnson, "A Further Opportunity for Fly Ash Utilization in Cement Production," *Proceedings of the Fourth International Ash Utilization Symposium* (March 1976).

[5] R. A. Fuessler, "Energy in Crisis and Transition," *Engineering News Record, Probing the Future* (April 30, 1974).

[41.4 × 10^3 N/cm^2]). Fly ash can be used to replace a portion of the cement in concrete and, through pozzolanic action, add strength to the concrete. High-strength rebars can be used to reduce the volume of reinforcing steel in reinforced concrete.

Fly ash is a powdered ash which results from the combustion of pulverized coal. Being a by-product of energy production, fly ash essentially has a zero energy intensity. Despite its potential for decreasing the cement requirement of a given concrete, only a fraction (approximately 10 percent) of the fly ash produced annually from the operation of coal-fired steam-generating stations is used. In 1975, approximately 42.3 × 10^6 tons (3.8 × 10^{10} kg) were produced, but only 4.5 × 10^6 tons (4.1 × 10^9 kg) were put to use.[6]

By reducing the amount of energy required to produce a unit volume of concrete, fly ash can reduce the energy intensity and cost of concrete. The energy savings from substitution of fly ash for 10 percent of the Type I cement produced in the United States would be 3.98 × 10^{13} Btu (4.20 × 10^{16} J) per year[7] equivalent to about 6.9 million barrels of crude oil. Compared to the more conventional Grade 40 rebars, high-strength rebars (Grade 60 and above) permit use of a smaller volume of steel to perform the same function. Since the amount of energy required to produce high-strength rebars is not significantly different from that required to produce standard rebars, use of high-strength rebars conserves energy. In addition, it has been determined that structures using high-strength rebars can exhibit gracefulness, resist high overloading, and be economical as well.[8] The Concrete Reinforcing Steel Institute recommends Grade 60 reinforcing steel as the standard grade for economy.[9]

Mode of Technology Transfer

The information presented in this report may be used as a guide for updating Corps of Engineers and Department of the Army manuals. The following changes are suggested:

1. Engineer Manual (EM) 1110-2-2000, *Standard Practice for Concrete*, paragraph 2-1b "During the planning stage of a project, consideration should be given to the applicability of fly ash and other pozzolans, and special cements."

2. Technical Manual (TM) 5-809-2, *Concrete Structural Design for Buildings*, paragraph 2, Basis for Design "When commercially available, consideration should be given during the concrete mix design stage to the use of fly ash as a replacement for a portion of the portland cement."

Paragraph 5, Design Choices—"Consideration shall be given to the use of Grade 60 reinforcing bars in place of Grade 40."

3. Guide Specification CE 1401.01, *Standard Guide Specifications for Concrete*, paragraph*_ _-5. __ Pozzolan "Fly ash shall be used to replace a portion of the portland cement, not to exceed __ percent by weight."

2 FLY ASH USE

Evaluation of Economic Benefit

The Economic Model

To properly determine the economic advantage of using fly ash in concrete, a cost and energy comparison of two hypothetical concrete mixes was performed. One mix was a control mix containing no fly ash and the other was a fly ash mix proportioned for equal performance and maximum economy. The design parameters used (Table 1) are rather standard for most purposes; however, these relationships should be reevaluated for extremely high- or low-strength concrete. Based on these parameters, the control mix was proportioned as shown in Table 2; the ACI mix proportioning method[10] was used.

The Tennessee Valley Authority (TVA) mix proportioning method[11] was used for the fly ash mixes. The governing factor in the determination of economic

[6] J. Faber, "U. S. Overview of Ash Production and Utilization," *Proceedings of the Fourth International Ash Utilization Symposium* (March 1976).

[7] J. E. Funnel and D. Johnson, "A Further Opportunity for Fly Ash Utilization in Cement Production," *Proceedings of the Fourth International Ash Utilization Symposium* (March 1976).

[8] ACI Committee 439, "Uses and Limitations of High Strength Steel Reinforcement," *ACI Journal, Proceedings*, Vol 70, No. 2 (February 1973), pp 77-104.

[9] *CRSI Handbook* (Concrete Reinforcing Steel Institute, 1972).

[10] ACI Committee 211, "Recommended Practice for Selecting Proportions for Normal Weight Concrete," *ACI Journal, Proceedings*, Vol 66, No. 8 (August 1969), pp 612-628.

[11] R. W. Cannon, "Proportioning Fly Ash Concrete Mixes for Strength and Economy," *ACI Journal, Proceedings*, Vol 68, No. 12 (November 1968), pp 969-979.

Table 1

Design Parameters

28-day compressive strength	3000 psi (2068 N/cm²)
Slump	3 in. (7.6 cm)
Percent air content	5%
Maximum size coarse aggregate	1 in. (2.5 cm)
Specific gravity of sand	2.65
Specific gravity of coarse aggregate	2.67
Dry rodded unit weight of coarse aggregate	104 lb/cu ft (1666 kg/m³)
Fineness modulus of sand	2.6

Table 2

Proportioning of Control Mix

Constituent	Weight, lb (kg)
Cement	500 (227)
Sand	1118 (507)
Coarse Aggregate	1937 (879)
Water	295 (134)

fly ash mix proportioning is the cost of fly ash as a percentage of the cost of cement. Figures 1 through 3 show the relationships between fly ash/cement cost percentage and fly ash required, sand saved, and cement saved, respectively. These curves were obtained by incrementing the fly ash/cement cost percentage in the TVA fly ash mix proportioning method and comparing the amounts of the constituents in the control and fly ash concrete mixes. These curves reach zero at 58 percent because for the given strength, workability, and durability requirements, the use of fly ash in concrete at fly ash/cement cost percentages greater than that would result in increased costs. Where this condition was encountered, fly ash use was assumed to be infeasible.

The cost differential between the two mixes was computed for each military installation in the United States based on the delivered (FOB plus transportation) cost of the constituents. It was assumed that cement and aggregate would be readily obtainable within a 20-mi (32 km) radius of all military installations, but that the major portion of the delivered fly ash cost would be freight. Thus, the actual transportation distances between military installations and fly ash sources were used in computing the delivered fly ash prices. All freight rates were based on bulk truck transport.

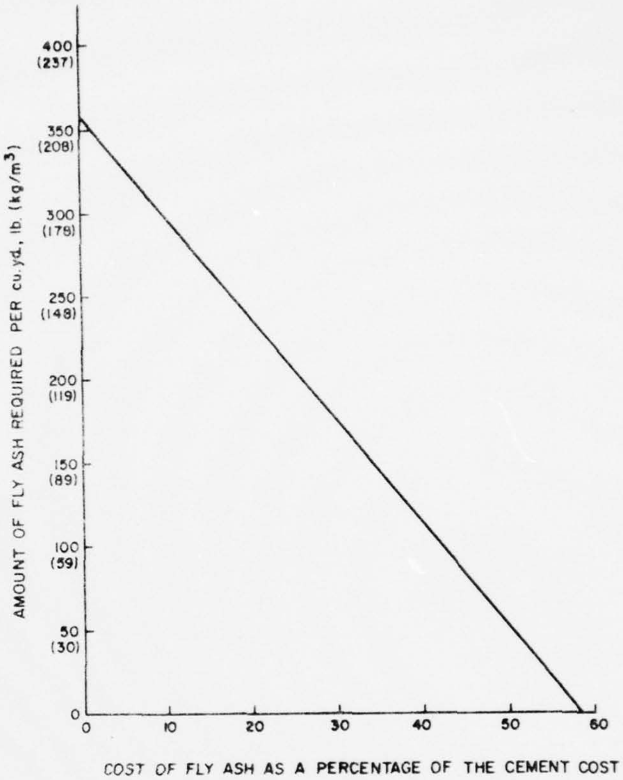

Figure 1. Relationship between fly ash cost as a percentage of the cement cost and the fly ash required for the given mix.

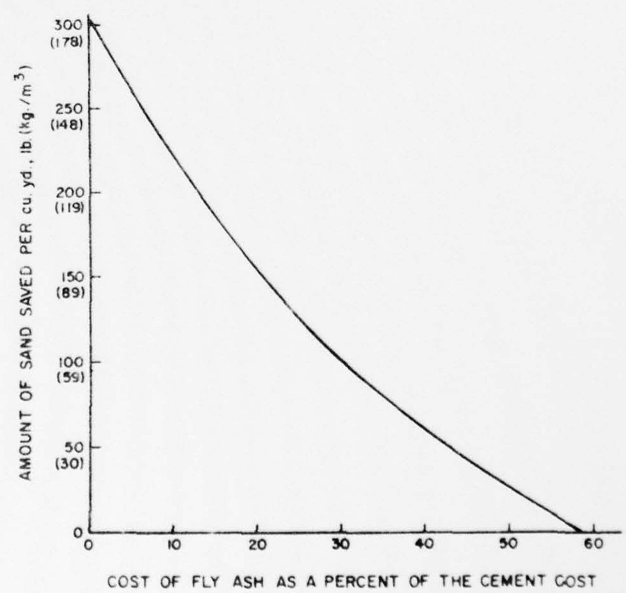

Figure 2. Relationship between fly ash cost as a percentage of cement cost and sand saved for the given mix.

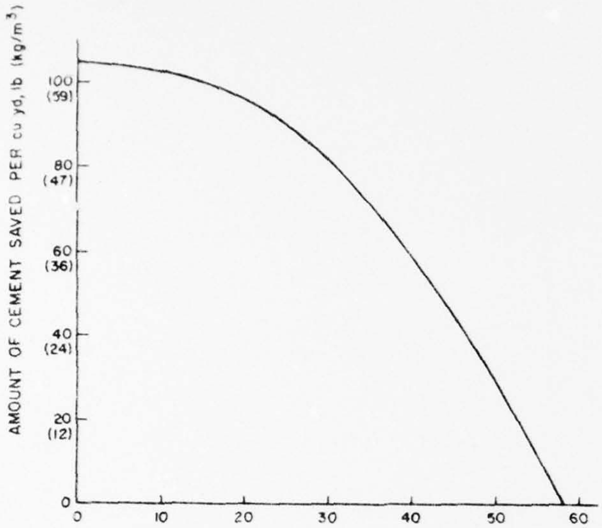

Figure 3. Relationship between fly ash cost as a percentage of the cement cost and cement saved for the mix.

Process and total energy differentials were computed on the basis of (1) energy saved through the use of less cement, (2) energy required to process the fly ash, (3) energy saved through smaller sand requirements, and (4) energy required to transport the fly ash.

Collection of Cost and Availability Data

The cost and availability of suitable quality fly ash were determined by contacting coal users who consume a minimum of about 1×10^6 tons (9.1×10^8 kg) of coal per year. These users, who were identified by consulting the *1975 Keystone Coal Industry Manual*[12] were considered to be major producers of fly ash. Each user was asked the following questions:

1. Is the fly ash produced of a suitable quality to be used as a pozzolan in concrete, and if so, does it meet either American Society for Testing and Materials (ASTM) or Corps of Engineers (CE) specifications?

2. If the fly ash is suitable as a pozzolan, is it being used as such, and if not, why?

3. If the fly ash is sold for pozzolanic purposes, what is the FOB price and freight rate?

[12] *1975 Keystone Coal Industry Manual* (McGraw-Hill Mining Publications, Mining Informational Services, 1975).

Where producers were selling their fly ash to brokers and therefore could not supply all needed information, the brokers were also contacted.

Based on these contacts, fly ash producers considered to be suitable fly ash sources were determined; producers considered suitable sources were those who either produce or sell fly ash which meets or exceeds ASTM or CE specifications, those who produce and/or sell fly ash which has recently been or is being used successfully as a pozzolan in concrete, and those who will be producing suitable fly ash in the near to immediate future pending installation of collection equipment. For sources which do not currently sell fly ash but were used in the analysis, the cost of the fly ash was estimated according to the going area price.

The major fly ash source closest to each military installation in the United States was chosen. The distances between the fly ash sources and the military installations were determined by direct map scaling and use of a mileage table for military locations in the United States.[13]

Because the freight for fly ash was found to be rather uniform throughout the United States, a representative freight rate-distance relationship (Figure 4) was used to determine the freight cost of fly ash.

The costs of portland cement and sand were determined by consulting a construction material price listing.[14] Area, city, and mill prices were used for the cement cost determinations, while an average price of \$4/ton (\$0.0044/kg) was used for sand. A flat rate was used to estimate the freight cost of cement and sand. Based on a 20-mi (32-km) radius of availability and current freight rates, the freight rates for cement and sand were assumed to be \$3/ton (\$0.0033/kg) and \$1.50/ton (\$0.0017/kg) respectively.

The energy consumed by truck transportation of materials was taken as 2,300 Btu/ton-mi (1,700 J/kg-km).[15] As indicated in Chapter 1, the process energy requirements of cement, sand, and fly ash are 7.9×10^6 Btu/ton (9.1×10^6 J/kg), 72×10^3 Btu/ton (84×10^3 J/kg), and zero.

[13] *Official Table of Distances* (Departments of the Army, Navy, and Air Force, January 1976).

[14] "Materials Prices," *Engineering News Record* (January 6, 1977).

[15] E. Hirst, "Energy Intensiveness of Transportation," *ASCE Transportation Engineering Journal*, Vol 9, No. TE1 (February 1973).

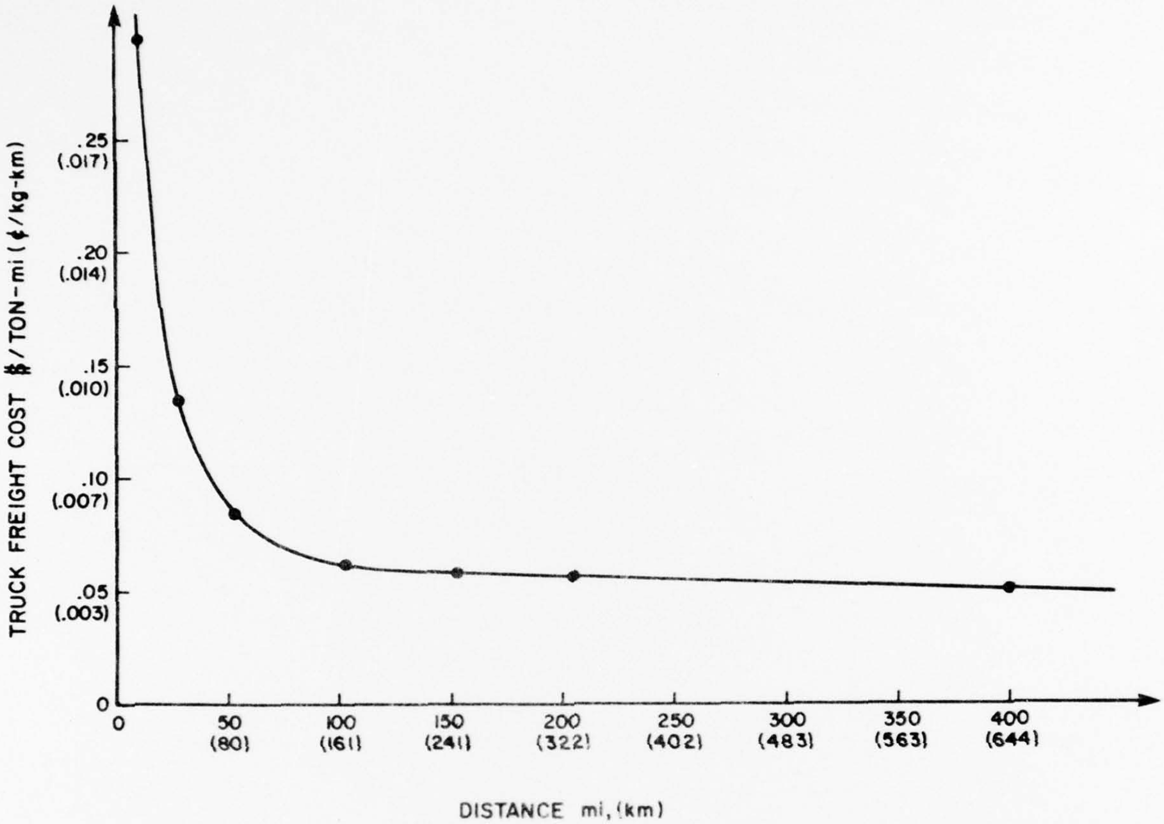

Figure 4. Fly ash freight rate curve.

Results

Fly Ash Source Survey

A total of 156 power plants in the United States were found to consume in excess of 1×10^6 tons (9.1×10^8 kg) of coal annually. The results of the survey of these plants can be summarized as follows:

1. Seventy-six of the plants sell fly ash which is suitable for use as a pozzolan in concrete. Of these, 21 meet ASTM and CE specifications, 48 meet only ASTM specifications, and seven produce fly ash which performs well as a pozzolan but has not been classified. All of these plants were used in the economic analysis.

2. Twenty-eight do not sell fly ash but could, since the fly ash they produce is or will be suitable for use as a pozzolan. Of these, the 21 who expect to be marketing fly ash in the near to immediate future were considered to be sources of suitable fly ash and were used in the economic analysis.

3. Fifty-two do not sell fly ash for pozzolanic purposes because of its low quality. Of these, 32 produce unsuitable fly ash and 20 produce fly ash which is of unknown or questionable quality.

The average cost of suitable fly ash is \$5.81/ton (\$0.0064/kg). The price ranges from \$1.50/ton (\$0.0017/kg) to \$21.60/ton (\$0.0238/kg).

Fly ash is most plentiful in the area east of the Mississippi River. Fly ash sources are scarce in Hawaii, Alaska, and most areas of the west, as the fly ash availability map in Figure 5 shows. There are 73, 123, and 216 military installations within 25, 100, and 500 mi (40, 161, and 805 km) respectively, of a significantly large source of suitable fly ash. Twenty-six installations—most in Hawaii and Alaska—are over 500 mi (805 km) from a suitable fly ash source.

Figure 5. Location of significantly large sources of suitable fly ash.

Economic Analysis

The appendix presents the dollar amounts which could be saved through the use of fly ash at military installations throughout the United States. It was determined that for the given fly ash concrete mix, a positive cost savings would result for 78 percent of all military installations in the United States. The average cost savings at these installations would be \$.87/cu yd (\$1.14/m^3), while the maximum savings would be \$2.10/cu yd (\$2.75/m^3). Use of fly ash in concrete is infeasible for the remaining 22 percent of military installations in the United States. For these installations, the fly ash/cement cost percentage is equal to or greater than 58 percent, which is the point at which use of fly ash loses any economic advantages (see Figures 1 through 3). The general geographic locations in which this condition exists are Hawaii, Alaska, many parts of the west, and parts of Maine and New York.

Since the effect of fly ash use on the process energy intensity of concrete depends largely on the amount of cement and sand saved, a simple relationship exists between the fly ash/cement cost percentage and the amount of process energy saved. Since the average fly ash/cement cost percentage can be calculated, the average process energy saving can therefore be obtained. Figure 6 is a plot of process energy savings vs. fly ash/cement cost percentage. The process energy saving for a particular installation can be obtained by first determining the fly ash/cement cost percentage from the appendix and then reading the corresponding value

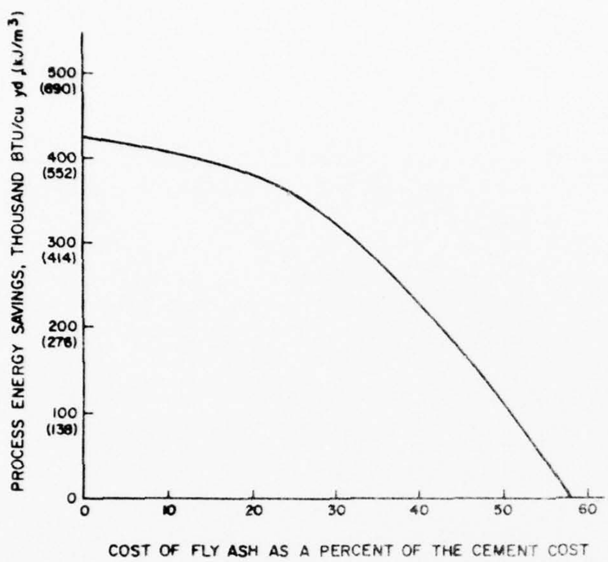

Figure 6. Process energy savings for the given fly ash concrete mix.

from Figure 6. Based on the fact that the average fly ash/cement cost percentage below 58 percent was 31.5 percent, the average process energy savings for the military installations at which the use of fly ash is feasible would be 3.12×10^5 Btu/cu yd (4.31×10^8 J/m^3) of concrete.

Determination of the total energy intensity involves the comparison of process energy intensity with transportation energy intensity. The total energy savings computed for each military installation are also reported in the appendix. Although it was expected that the transportation energy required to move the fly ash over large distances might cancel out the process energy savings in some cases, this did not prove to be true. The average total energy savings was found to be 2.72×10^5 Btu/cu yd (3.75×10^8 J/m^3). This energy savings per cubic yard is sufficient to heat the average 1200 sq ft (112 m^2) home in the state of Illinois for 14 hours. The yearly energy requirements for 236,000 households (3.98×10^{13} Btu [4.20×10^{16} J]) can be supplied with the energy savings that would accrue by substituting fly ash for 10 percent of all Type I cement produced in the United States each year.

The appendix also presents the potential cement savings per cubic yard of concrete. The average savings would be 73 lb/cu yd (47 kg/m^3) and the maximum savings would be 102 lb/cu yd (61 kg/m^3) of concrete.

It should be noted that only truck transportation of materials was considered in this investigation. If large quantities of fly ash are required over long distances, either rail or barge transit will help increase the advantages of using fly ash with respect to energy and cost savings, since truck transportation, although usually more convenient, is by far the most costly and inefficient of the three modes of bulk material transit.

The advantages of using fly ash in concrete can also be increased by specifying 90-day strengths instead of 28-day strengths whenever possible. The amount of cement which can be replaced by fly ash depends on the strength gain characteristics required of the concrete. Since the strength gain in fly ash concrete is slower than plain concrete, the time at which the specified strength is required has a direct effect on the amount of fly ash used in the concrete.

Other Considerations

In addition to conserving materials and energy, fly ash has other properties which must be considered. Fly ash also improves the quality of concrete. Among the properties which can be improved are workability, heat of hydration and thermal shrinkage reduction, resistance to sulfate attack, and reduction of alkali-aggregate reaction.[16] Projects constructed using fly ash concrete include the Sears Tower, John Hancock Building, and Water Tower Place in Chicago, IL, and the Ruan Building in Des Moines, IA. Fly ash concrete is routinely specified for all very tall buildings in the Chicago area.

There are, of course, some problems associated with use of fly ash. These include (1) the high capital investment required to install additional material-handling equipment at the coal-burning and batching plants, (2) the lack of realistic guide specifications for fly ash use, (3) the relative unavailability of fly ash in some areas of the United States, and (4) the varying quality of fly ash from plant to plant (not all fly ash is suitable for use in concrete).

[16] W. H. Price, "Pozzolans—A Review," *ACI Journal, Proceedings*, Vol 72, No. 5 (May 1975), pp 224-232.

3 HIGH STRENGTH REBARS

Considerations Affecting Cost and Energy Savings

As indicated in Chapter 1, the advantage of using high-strength rebars is reduction in the volume of steel and associated process energy required to perform a given structural function.* For example, two Grade 40 #8 rebars which resist a tensile load of 63.2 kips (281 kN) at yield stress can ideally be replaced by one Grade 80 #8 rebar, which can restrain the same load at yield stress. However, this reduction does not automatically produce an equivalent cost reduction, since high-strength rebars are more costly than nominal Grade 40 rebars. In addition, the extent to which ideal volume reduction potentials can be realized greatly depends on the compatibility of high-strength rebars with concrete.

Various conditions involving the interactions between concrete and rebars are expected to have an impact on the material and cost savings associated with the use of high-strength rebars. Among these conditions are (1) longer lap splicing length, (2) longer development lengths, (3) smaller reinforcing bar spacings, and (4) larger deflections.[17] The ACI Building Code Requirements for Reinforced Concrete (ACI 318-71)[18] state the provisions for designing reinforced concrete with high-strength rebars. The ACI Building Code's treatment of high-strength rebars was examined to evaluate their advantages.

Technical and Economic Factors Associated With High-Strength Rebar Use

An overview of various sources regarding the potential of high-strength rebar indicated the following trends:

1. The most important step in conservation of reinforcing steel is the use of Grade 60 rebar in place of Grade 40 rebar. This procedure will save 20 to 25 percent of the steel that would otherwise have been required; although this estimate is based on the ultimate strength design method, there is a potential for even greater savings if the working stress design method is used.[19]

2. The significance of the effect of high-strength rebar on the ultimate load capacity of columns increases with column size.[20, 21]

3. Use of high-strength concrete is more effective in reducing the costs of columns than is use of high-strength rebar.[22]

4. In reinforced concrete beams and structural slabs, the use of higher-strength rebars (greater than Grade 60) can significantly reduce both steel volume and costs.[23, 24]

As indicated in Chapter 1, Grade 60 rebars have been recommended as the standard grade for economy. Although high-strength rebars cost more, they still offer the potential for overall cost reduction. Based on the above 25 percent maximum potential volume savings when Grade 60 rebar is substituted for Grade 40 rebar, the corresponding cost reduction is on the order of 15 percent. This is based on material prices of \$400 and \$410/ton (\$0.44 and \$0.45/kg) for Grades 40 and 60, respectively, and a placement cost of \$236/ton (\$0.26/kg) for both types of rebar.[25] The 25 percent substitution would have an associated process energy savings of 10.8×10^6 Btu/ton (12.6×10^6 J/kg) of Grade 60 rebar used.

Rice and Gustatson[26] have speculated that using higher strength, possibly Grade 80, rebars may offer even greater advantages. Although these rebars are not

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*The difference between high-strength rebars and nominal Grade 40 rebars is chemical composition, not processing.

[17] P. F. Rice and D. P. Gutstatson, "Grade 80 Reinforcing Bars and ACI 318-71," *ACI Journal, Proceedings*, Vol 73, No. 4 (April 1976), pp 199-206.

[18] *Building Code Requirements for Reinforced Concrete*, ACI 318-71 (American Concrete Institute, 1971).

[19] "The Efficient Use of Reinforcing Steel," *Concrete Construction*, Vol 19, No. 6 (June 1974).

[20] ACI Committee 439, "Uses and Limitations of High Strength Steel Reinforcement," *ACI Journal, Proceedings*, Vol 70, No. 2 (February 1973), pp 77-104.

[21] Rice and Gustatson.

[22] ACI Committee 439.

[23] ACI Committee 439.

[24] Rice and Gustatson.

[25] *Building Construction Cost Data*, 35th edition (Robert Snow Means Company, Inc., 1977).

[26] Rice and Gustatson.

yet available except by special agreement, the potential advantages are worth considering. The impact of higher unit prices on the feasibility of high-strength rebar does, however, appear to increase with increasing strengths. Rice and Gutstatson's comparison of Grade 80 and Grade 60 rebars has indicated that a steel volume savings of 12 percent will just begin to show positive cost savings. It has also been estimated that the maximum practical material savings of 21 percent would result in a cost savings of 11 percent.[27] Combining these figures with those for the Grade 60 substitution indicates that the maximum practical material savings available when Grade 80 is substituted for Grade 40 is 41 percent. However, the resulting cost savings would be only 24 percent. The potential for process energy savings through the use of Grade 80 rebar is consequently 9×10^6 Btu/ton (10.5×10^6 J/kg) of Grade 80 used in place of Grade 60 rebar, and 17.6×10^6 Btu/ton (20.5×10^6 J/kg) of Grade 80 used in place of Grade 40 rebar.

Aside from higher material prices, design requirements also tend to make use of high-strength rebar somewhat less attractive. Development lengths must be increased for high-strength rebars. Since adequate development length is directly related to the force in the rebar, if one increases, the other must also increase. The same relationship results for lap splicing, since this is simply a form of development length. Increased development and lap splicing length therefore increase the volume of steel and thus have a negative effect on economy.

The increase in development length and lap splicing length is directly related to the yield strength of the steel. However, this relationship changes for rebars over Grade 60. In the comparison of Grade 80 with Grade 60 rebars, it has been found that the ACI code specifies the following increases in development and lap splicing lengths for Grade 80 rebars:[28]

1. Tension development length 67 percent
2. Compression development length 33 percent
3. Tension lap splicing length 67 percent
4. Compression lap splicing length 60 percent.

Serviceability requirements which tend to nullify the cost and resource savings associated with the use of high-strength rebars are (1) control of deflections and (2) distribution of flexural reinforcement. Larger deflections generally result when designing flexural members with high-strength rebars, since either shallower depths of section are required or less steel is necessary.[29] Both of these conditions tend to reduce the moment of inertia of the section and consequently increase deflection. Greater costs and resource intensities can result when the design of a flexural member is governed by deflection requirements. Deeper sections can result, more steel may be required, and more time is spent in the design of such members.

The control of cracking in flexural members is provided for in the distribution of flexural reinforcement requirement, which specifies the maximum allowable spacing between adjacent rebars. This requirement is designed to keep crack widths small enough to deter corrosion. The crack control requirements are expected to be more severe for high-strength rebars, since the steel stress is higher and fewer rebars are required,[30] two conditions which are known to be directly related to cracking in reinforced concrete flexural members. Maximum bar spacing limitations may increase costs by increasing the volume of steel required or by increasing placement costs due to the use of a larger number of small diameter rebars.

Thus, although high-strength rebars do have potential for reducing the amount of steel used and consequently energy consumed in processing, the reward for saving steel and energy (i.e., cost reduction) may not always be obtainable due to higher material prices and design restrictions set forth by building codes. However, the literature indicates that use of high-strength rebar in the following structural elements is expected to result in material, energy, and cost reduction: (1) beams, joists, and thick slabs, especially those with high steel percentages, noncritical deflections, and interior exposure, and (2) two-way structural slabs which have high loads, long spans, and interior exposure.[31, 32]

[27]P. F. Rice and D. P. Gustatson, "Grade 80 Reinforcing Bars and ACI 318-71," *ACI Journal, Proceedings*, Vol 73, No. 4 (April 1976), pp 199-206.

[28]Rice and Gustatson.

[29]Rice and Gustatson.

[30]ACI Committee 439, "Uses and Limitations of High Strength Steel Reinforcement," *ACI Journal, Proceedings*, Vol 70, No. 2 (February 1973), pp 77-104.

[31]Rice and Gustatson.

[32]ACI Committee 439.

4 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This investigation indicated that use of fly ash and high-strength rebar in military construction can result in significant energy and materials savings. In addition, these alternates can in many instances result in considerable cost savings.

With respect to fly ash use, it was estimated that positive cost savings would result for 78 percent of the major military installations in the United States. The average cost savings would be \$.87/cu yd (\$1.14/m^3) of fly ash concrete used, and the maximum cost savings would be \$2.10/cu yd (\$2.75/m^3). Among the military installations at which the use of fly ash would result in positive cost savings, the average amount of process energy which may be conserved is 3.12×10^5 Btu/cu yd (4.31×10^8 J/m^3) of fly ash concrete used, while the average total energy savings would be 2.72×10^5 Btu/cu yd (3.75×10^8 J/m^3) of fly ash concrete used.

Use of high-strength rebar is expected to result in positive cost, material, and energy savings when used in (1) beams, joists, and thick slabs with high steel percentages, noncritical deflections, and interior exposure, and (2) two-way structural slabs with high loads, long spans, and interior exposure. At present, the maximum practical cost savings of Grade 60 rebar over Grade 40 rebar was found to be 15 percent, with a corresponding material savings of 25 percent. Use of Grade 80 rebars in place of Grade 40 rebars was found to have a maximum practical cost savings of 24 percent and a corresponding material savings of 41 percent. The potential for process energy conservation was found to be a maximum of 10.8×10^6 Btu/ton (12.6×10^6 J/kg) of Grade 60 used in place of Grade 40 and 17.6×10^6 Btu/ton (20.5×10^6 J/kg) of Grade 80 used in place of Grade 40 rebar.

Recommendations

It is recommended that fly ash and high-strength rebar be considered for present and future construction projects and that TM 5-809-2, CE 1401.01, and EM 1110-2-2000 be revised to facilitate use of these alternates.

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APPENDIX:
FLY ASH USE DATA

Table A1

Data for Army Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd (m³)	Total Energy Savings Btu/cu yd (kJ/m³)	Cement Savings lb/cu yd (kg/m³)
Aberdeen Proving Ground Aberdeen, MD	Eddystone Station Eddystone, PA	70 (113)	17	1.57 (2.05)	370,162 (510,809)	98 (58)
Anniston Army Depot Anniston, AL	E. C. Gaston Plant Wilsonville, AL	50 (80)	24	1.23 (1.61)	355,016 (489,908)	92 (55)
Arlington Hall Station Arlington, VA	Potomac River Plant Alexandria, VA	7 (11)	18	1.60 (2.09)	388,578 (536,223)	98 (58)
Army Matl's & Mech. Research Center Watertown, MA	Merrimac Plant Concord, NH	70 (113)	59			
Badger Army Ammunition Plant Baraboo, WI	Oak Creek Plant Oak Creek, WI	117 (188)	29	.92 (1.20)	308,319 (425,468)	84 (50)
Baker, Fort Sausalito, CA	Mohave Plant Laughlin, NV	500 (805)	64			
Bayonne Military Ocean Terminal Bayonne, NJ	Mercer Plant Hamilton Twp., NJ	57 (92)	61			
Belvoir, Fort Alexandria, VA	Potomac River Plant Alexandria, VA	10 (16)	18	1.60 (2.09)	387,715 (535,032)	98 (58)
Benning, Fort Columbus, GA	Yates Plant Newman, GA	81 (130)	25	1.12 (1.46)	388,189 (535,686)	90 (53)
Bliss, Fort El Paso, TX	Navajo Plant Page, AZ	470 (756)	70			
Blue Grass Depot Activity Richmond, KY	Cane Run Plant Louisville, KY	75 (121)	22	1.18 (1.46)	354,361 (489,004)	94 (56)
Bragg, Fort Fayetteville, NC	Roxboro Plant Roxboro, NC	103 (165)	29	.96 (1.19)	311,330 (429,623)	84 (50)
Brooke Army Medical Center San Antonio, TX	Big Brown Plant Fairfield, TX	194 (312)	34	.72 (.89)	258,930 (357,313)	74 (44)
Cameron Station Alexandria, Va	Potomac River Plant Alexandria, VA	10 (16)	18	1.60 (1.98)	387,715 (535,032)	98 (58)
Campbell, Fort Clarksville, TN	Gallatin Steam Plant Gallatin, IN	84 (135)	20	1.30 (1.61)	359,196 (495,676)	96 (57)
Carlisle Barracks Carlisle, PA	Dickerson Plant Dickerson, MD	110 (177)	33	.70 (.87)	283,392 (391,070)	76 (45)

Table A1 (Cont'd)

Data for Army Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd (m³)	Total Energy Savings Btu/cu yd (kJ/m³)	Cement Savings lb/cu yd (kg/m³)
Carson, Fort Colorado Springs, CO	Cherokee Steam Plant Denver, CO	78 (126)	18	1.73 (2.14)	368,165 (508,053)	98 (58)
Chaffae, Fort Fort Smith, AR	LaCygne Station LaCygne, KS	253 (407)	40	.41 (.51)	198,821 (274,365)	59 (35)
Defense Const. Supply Center Columbus, OH	F. M. Tait Plant Dayton, OH	81 (130)	27	.97 (1.20)	326,985 (451,227)	87 (52)
Defense Depot Memphis, TN	T. H. Allen Plant Memphis, TN	10 (16)	12	2.10 (2.60)	403,254 (556,475)	102 (61)
Defense Depot Ogden, UT	Navajo Plant Page, AZ	305 (491)	53	.04 (.05)	62,659 (86,467)	19 (11)
Defense General Supply Center Richmond, VA	Morgantown Plant Morgantown, MD	84 (135)	27	1.02 (1.26)	326,295 (450,274)	87 (52)
Defense Personnel Support Center Philadelphia, PA	Eddystone Station Eddystone, PA	10 (16)	11	2.07 (2.57)	404,598 (558,329)	102 (61)
Detrick, Fort Frederick, MD	Dickerson Plant Dickerson, MD	43 (69)	26	1.00 (1.24)	339,583 (468,611)	88 (52)
Detroit Arsenal Detroit, MI	Trenton Channel Plant Trenton, MI	25 (40)	14	1.70 (2.11)	391,434 (540,164)	100 (59)
Devens, Fort Ayer, MA	Merrimac Plant Concord, NH	36 (58)	57	0 (0)	15,441 (21,308)	4 (2)
Dix, Fort Trenton, NJ	Mercer Plant Hamilton Twp., NJ	5 (8)	59			
Drum, Fort Watertown, NY	Merrimac Plant Concord, NH	330 (531)	86			
Dugway Proving Ground Dugway, UT	Navajo Plant Page, AZ	395 (636)	61			
Eustis, Fort Warwick, VA	Roxboro Plant Roxboro, NC	201 (323)	41	.34 (.42)	194,735 (268,727)	56 (33)
Fitzsimons Army Medical Center Aurora, CO	Cherokee Steam Plant Denver, CO	10 (16)	13	2.09 (2.59)	400,248 (522,327)	101 (60)
Frankfort Arsenal Philadelphia, PA	Eddystone Station Eddystone, PA	5 (8)	11	2.07 (2.57)	406,470 (560,913)	102 (61)
Gillem, Fort Forest Park, GA	Wansley Plant Newnan, GA	30 (48)	21	1.36 (1.69)	370,232 (510,906)	95 (56)

Table A1 (Cont'd)

Data for Army Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Dis-tance mi (km)	Fly Ash/ Cement Cost Per-centage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Gordon, Fort Augusta, GA	Harllee Branch Plant Eatonton, GA	136 (219)	31	.79 (.98)	290,086 (400,307)	80 (47)
Greely, Fort Delta Junction, AK	Centrailia Plant Centrailia, WA	2220 (3573)	130			
Hamilton, Fort New York, NY	Mercer Plant Hamilton Twp., NJ	59 (95)	61			
Harrison, Fort Benjamin Indianapolis, IN	E. W. Stout Plant Indianapolis, IN	10 (16)	21	1.44 (1.79)	375,522 (518,206)	95 (56)
Harry Diamond Labs. Silver Spring, MD	Dickerson Plant Dickerson, MD	5 (8)	21	1.39 (1.72)	376,845 (520,031)	95 (56)
Hill, Fort A. P. Bowling Green, VA	Morgantown Plant Morgantown, MD	22 (35)	23	1.28 (1.59)	364,268 (502,676)	93 (55)
Holston Army Ammo Plant Kingsport, TN	Clinch River Plant Carbo, VA	32 (51)	27	.94 (1.17)	338,255 (466,779)	87 (52)
Hood, Fort Killeen, TX	Big Brown Plant Fairfield, TX	102 (164)	26	.99 (1.23)	325,674 (449,417)	88 (52)
Houston, Fort Sam San Antonio, TX	Big Brown Plant Fairfield, TX	204 (328)	40	.39 (.48)	205,583 (283,697)	59 (35)
Huachuca, Fort Sierra Vista, AZ	Mohave Plant Laughlin, NV	352 (566)	62			
Hunter Army Airfield Savannah, GA	Wateree Plant Eastover, SC	134 (216)	35	.59 (.73)	258,060 (356,113)	71 (42)
Indiana Army Ammo Plant Charleston, IN	Cane Run Plant Louisville, KY	15 (24)	18	1.45 (1.90)	386,278 (533,049)	98 (58)
Indiantown Gap, Fort Lebanon, PA	Eddystone Station Eddystone, PA	77 (124)	16	1.68 (2.20)	371,747 (512,996)	99 (59)
Iowa Army Ammo Plant Burlington, IA	Powerton Plant Pekin, IL	94 (151)	19	1.54 (2.01)	360,181 (497,036)	97 (58)
Irwin, Fort Barstow, CA	Mohave Plant Laughlin, NV	163 (261)	39	.45 (.59)	221,776 (360,042)	62 (37)
Jackson, Fort Columbia, SC	Wateree Plant Eastover, SC	30 (48)	24	1.21 (1.58)	358,364 (494,528)	92 (55)
Jefferson Proving Ground Madison, IN	Cane Run Plant Louisville, KY	54 (87)	19	1.47 (1.92)	371,451 (512,588)	97 (58)
Joliet Army Ammo Plant Joliet, IL	Joliet Plant Joliet, IL	15 (24)	23	1.25 (1.63)	366,056 (505,143)	93 (55)

Table A1 (Cont'd)

Data for Army Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/ Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Kansas Army Ammo Plant Parsons, KS	LaCygne Plant LaCygne, KS	105 (169)	28	.97 (1.26)	314,221 (433,613)	85 (50)
Knox, Fort Radcliff, KY	Cane Run Plant Louisville, KY	33 (53)	18	1.41 (1.84)	381,103 (525,907)	98 (58)
Lake City Army Ammo Plant Independence, MO	Hawthorne Station Kansas City, MO	20 (32)	23	1.28 (1.67)	364,779 (503,381)	93 (55)
Leavenworth, Fort Leavenworth, KS	Hawthorne Station Kansas City, MO	35 (56)	24	1.23 (1.61)	357,122 (492,814)	92 (55)
Lee, Fort Petersburg, VA	Morganstown Plant Morgantown, MD	80 (129)	27	1.03 (1.35)	327,215 (451,544)	87 (52)
Letterkenny Army Depot Chambersburg, PA	Dickerson Plant Dickerson, MD	70 (113)	28	.90 (1.18)	321,949 (444,277)	85 (50)
Letterman Army Medical Center San Francisco, CA	Mohave Plant Laughlin, NV	490 (789)	64			
Lewis, Fort Tacoma, WA	Centrailia Plant Centrailia, WA	38 (61)	31	.97 (1.27)	309,809 (427,524)	80 (47)
Lexington-Blue Grass Army Depot Lexington, KY	W. C. Beckjord Plant Richmond, OH	60 (97)	28	.89 (1.16)	324,157 (447,324)	85 (50)
Liggett, Fort Hunter King City, CA	Mohave Plant Laughlin, NV	380 (612)	57	0	12,226 (16,871)	4 (2)
Lone Star Army Ammo Plant Texarkana,, TX	Big Brown Plant Fairfield, TX	160 (257)	29	.95 (1.24)	299,072 (412,708)	84 (50)
Longhorn Army Ammo Plant Marshall, TX	Big Brown Plant Fairfield, TX	140 (255)	27	1.06 (1.39)	313,415 (432,500)	87 (52)
Louisiana Army Ammo Plant Minden, LA	Big Brown Plant Fairfield, TX	178 (286)	30	.94 (1.23)	288,471 (389,079)	82 (49)
Macall Camp Hoffman, NC	Allen Steam Plant Belmont, NC	80 (129)	27	1.03 (1.35)	327,215 (451,544)	87 (52)
Madigan Army Medical Center Tacoma, WA	Centrailia Plant Centrailia, WA	36 (58)	31	.97 (1.27)	310,211 (428,079)	80 (47)
McClellan, Fort Anniston, AL	Hammond Plant Coosa, GA	48 (77)	22	1.35 (1.77)	361,440 (498,773)	94 (56)
McCoy, Fort Sparta, WI	J. P. Pulliam Plant Green Bay, WI	130 (209)	23	1.46 (1.91)	336,696 (464,627)	93 (55)
McNair, Fort Lesley J. Washington, DC	Dickerson Plant Dickerson, MD	34 (55)	23	1.25 (1.63)	361,205 (498,449)	93 (55)

Table A1 (Cont'd)

Data for Army Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
McPherson, Fort Atlanta, GA	McDonough-Atkinson Plant Smyrna, GA	15 (24)	20	1.40 (1.83)	378,240 (521,956)	96 (57)
Meade, Fort Geo. G. Laurel, MD	Dickerson Plant Dickerson, MD	34 (55)	25	1.08 (1.41)	349,539 (482,350)	90 (53)
Michigan Army Missile Plant Sterling Heights, MI	St. Clair Plant Belle River, MI	30 (48)	14	1.68 (2.20)	389,853 (537,982)	100 (59)
Milan Army Ammo Plant Milan, TN	Johnsonville Plant Johnsonville, TN	50 (80)	15	1.82 (2.38)	383,678 (529,461)	100 (59)
Monmouth, Fort Red Bank, NJ	Mercer Plant Hamilton Twp., NJ	49 (79)	60			
Monroe, Fort Hampton, VA	Morgantown Plant Morgantown, MD	105 (169)	29	.93 (1.22)	310,900 (429,030)	84 (50)
Myer, Fort Arlington, VA	Potomac River Plant Alexandria, VA	10 (16)	18	1.60 (2.09)	387,715 (535,032)	98 (58)
Natick Development Center Natick, MA	Merrimac Plant Concord, NH	60 (97)	58			
Navajo Depot Activity Flagstaff, AZ	Navajo Plant Page, AZ	192 (309)	46	.14 (.18)	143,417 (197,910)	41 (24)
New Cumberland Army Depot Harrisburg, PA	Eddystone Station Eddystone, PA	80 (129)	16	1.66 (2.17)	370,843 (511,749)	99 (59)
Newport Army Ammo Plant Newport, IN	E. W. Stout Plant Indianapolis, IN	65 (105)	25	1.16 (1.52)	342,053 (472,020)	90 (53)
Oakland Army Base Oakland, CA	Mohave Plant Laughlin, NV	510 (821)	65			
Ord, Fort Seaside, CA	Mohave Plant Laughlin, NV	420 (676)	60			
Picatinny Arsenal Dover, NJ	Mercer Plant Hamilton Twp., NJ	52 (84)	61			
Pickett, Fort Blackstone, VA	Roxboro Plant Roxboro, NC	75 (121)	26	1.05 (1.37)	332,039 (458,201)	88 (52)
Pine Bluff Arsenal Pine Bluff, AR	T. H. Allen Plant Memphis, TN	125 (201)	20	1.52 (1.99)	347,880 (480,061)	96 (57)
Pohakuloa Training Area Hilo, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			

Table A1 (Cont'd)

Data for Army Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings \$/cu yd (m^3)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Polk, Fort Leesville, LA	Big Brown Plant Fairfield, TX	195 (314)	32	.80 (1.05)	271,788 (375,057)	78 (46)
Presidio of Monterey Monterey, CA	Mohave Plant Laughlin, NV	395 (636)	59			
Presidio of San Francisco San Francisco, CA	Mohave Plant Laughlin, NV	485 (781)	63			
Pueblo Army Depot Pueblo, CO	Cherokee Steam Plant Denver, CO	131 (211)	22	1.40 (1.83)	339,678 (468,742)	94 (56)
Radford Army Ammo Plant Radford, VA	Clinch River Plant Carbo, VA	87 (140)	27	1.00 (1.31)	325,605 (449,322)	87 (52)
Red River Army Depot Texarkana, TX	Big Brown Plant Fairfield, TX	170 (274)	31	.86 (1.12)	283,244 (390,866)	80 (47)
Redstone Arsenal Huntsville, AL	Colbert Steam Plant Pride, AL	75 (121)	17	1.67 (2.18)	368,690 (508,778)	98 (58)
Richardson, Fort Anchorage, AK	Centrailia Plant Centrailia, WA	2406 (3872)	140			
Riley, Fort Junction City, KS	Hawthorne Station Kansas City, MO	130 (209)	32	.77 (1.01)	284,346 (392,386)	78 (46)
Ritchie, Fort Blue Ridge Summit, PA	Dickerson Plant Dickerson, MD	52 (84)	26	.99 (1.29)	337,461 (465,683)	88 (52)
Riverbank Army Ammo Plant Riverbank, CA	Mohave Plant Laughlin, NV	400 (644)	56	.02 (.03)	24,644 (34,008)	8 (5)
Roberts, Camp Paso Robles, CA	Mohave Plant Laughlin, NV	350 (563)	55	.04 (.05)	39,230 (54,136)	12 (7)
Rock Island Arsenal Rock Island, IL	M. L. Kapp Plant Clinton, IA	25 (40)	24	1.17 (1.53)	359,606 (496,242)	92 (55)
Rocky Mountain Arsenal Denver, CO	Cherokee Steam Plant Denver, CO	10 (16)	13	2.09 (2.73)	400,248 (552,327)	101 (60)
Rucker, Fort Daleville, AL	Christ Steam Plant Pensacola, FL	115 (185)	36	.58 (.76)	254,349 (350,992)	69 (41)
Sacramento Army Depot Sacramento, CA	Mohave Plant Laughlin, NV	450 (724)	57	0	11,632 (16,052)	4 (2)
Saginaw Army Aircraft Plant Saginaw, TX	Big Brown Plant Fairfield, TX	110 (177)	24	1.26 (1.65)	338,492 (467,106)	92 (55)
Savanna Army Depot Savanna, IL	M. L. Kapp Plant Clinton, IA	25 (40)	24	1.17 (1.53)	359,606 (496,242)	92 (55)

Table A1 (Cont'd)

Data for Army Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/ Cement Cost Percentage	Cost Savings \$/cu yd (m^3)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Schofield Barracks Honolulu, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Scranton Army Ammo Plant Scranton, PA	Mercer Plant Hamilton Twp., NJ	136 (219)	69			
Seneca Army Depot Geneva, NY	Keystone Plant Shelocta, PA	210 (338)	40	.43 (.56)	204,755 (282,554)	59 (35)
Shafter, Fort Honolulu, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Sharpe Army Depot Stockton, CA	Mohave Plant Laughlin, NV	420 (675)	57	0	11,908 (16,443)	4 (2)
Sheridan, Fort Highland Park, IL	Waukegan #1 Plant Waukegan, IL	13 (21)	23	1.27 (1.66)	366,566 (505,847)	93 (55)
Sierra Army Depot Susanville, CA	Mohave Plant Laughlin, NV	475 (764)	59			
Sill, Fort Lawton, OK	Big Brown Plant Fairfield, TX	235 (378)	40	.41 (.54)	201,305 (277,793)	59 (35)
Stewart, Fort Hinesville, GA	Harllee Branch Plant Eatonton, GA	150 (241)	35	.57 (.75)	255,263 (352,353)	71 (42)
St. Louis Area Support Center Granite City, IL	Wood River Plant East Alton, IL	25 (40)	20	1.49 (1.95)	375,480 (518,148)	96 (57)
Story, Fort Virginia Beach, VA	Morgantown Plant Morgantown, MD	125 (201)	31	.79 (1.03)	292,300 (403,363)	80 (47)
Sunny Point Military Ocean Terminal Wilmington, NC	Wateree Plant Eastover, SC	203 (327)	41	.33 (.43)	194,466 (268,356)	56 (33)
Tarheel Army Missile Plant Burlington, NC	Roxboro Plant Roxboro, NC	35 (56)	23	1.25 (1.63)	360,950 (498,097)	93 (55)
Tobyhanna Army Depot Scranton, PA	Mercer Plant Hamilton Twp., NJ	85 (137)	63			
Tooele Army Depot Tooele, UT	Navajo Plant Page, AZ	225 (362)	45	.17 (.22)	150,263 (207,357)	44 (26)
Tripler Army Medical Center Honolulu, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Twin Cities Army Ammo Plant New Brighton, MN	Allen S. King Plant Stillwater, MN	15 (24)	19	1.74 (2.28)	382,439 (527,751)	97 (58)
Umatilla Depot Activity Hermiston, OR	Centrailia Plant Centrailia, WA	200 (322)	59			

Table A1 (Cont'd)

Data for Army Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Dis- tance mi (km)	Fly Ash/ Cement Cost Per- centage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Vint Hill Farms Station Warrentown, VA	Potomac River Plant Alexandria, VA	30 (48)	19	1.49 (1.95)	378,213 (521,919)	97 (58)
Volunteer Army Ammo Plant Chattanooga, TN	Hammond Plant Coosa, GA	65 (105)	24	1.20 (1.57)	349,670 (482,531)	92 (55)
Wadsworth, Fort New York, NY	Mercer Plant Hamilton Twp., NJ	63 (101)	61			
Wainwright, Fort Fairbanks, AK	Centrailia Plant Centrailia, WA	2270 (3653)	133			
Walter Reed Army Med. Center Washington, DC	Dickerson Plant Dickerson, MD	15 (24)	22	1.30 (1.70)	370,093 (510,714)	94 (56)
Watervilet Arsenal Watervilet, NY	Merrimac Plant Concord, NH	130 (209)	71			
West Point Military Reservation Newberg, NY	Mercer Plant Hamilton Twp., NJ	90 (145)	63			
White Sands Missile Range White Sands, NM	Navajo Plant Page, AZ	430 (692)	69			
William Beaumont Army Med. Center El Paso, TX	Navajo Plant Page, AZ	470 (756)	70			
Wood, Ft. Leonard Rolla, MO	Labadie Plant Labadie, MO	95 (153)	27	1.04 (1.36)	323,765 (446,783)	87 (52)
Yakima Firing Center Yakima, WA	Centrailia Plant Centrailia, WA	140 (255)	56	.02 (.03)	29,129 (40,197)	8 (5)
Yuma Proving Ground Yuma, AZ	Mohave Plant Laughlin, NV	170 (274)	42	.31 (.41)	192,245 (265,291)	54 (32)

Table A2

Data for Air Force Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Altus AFB Altus, OK	Big Brown Plant Fairfield, TX	280 (451)	44	.23 (.30)	158,678 (218,969)	48 (28)
Andrews AFB Camp Springs, MD	Chalk Point Aquasco, MD	10 (16)	21	1.39 (1.82)	375,522 (518,206)	95 (56)
Arnold Engineering Development Center Manchester, TN	Gallatin Steam Plant Gallatin, TN	80 (129)	18	1.56 (2.04)	367,590 (507,260)	98 (58)
Barksdale AFB Bossier City, LA	Big Brown Plant Fairfield, TX	170 (274)	31	.86 (1.12)	283,244 (390,866)	80 (47)
Beale AFB Marysville, CA	Mohave Plant Laughlin, NV	480 (772)	60			
Bergstrom AFB Austin, TX	Big Brown Plant Fairfield, TX	145 (233)	32	.73 (.95)	281,448 (388,387)	78 (46)
Blytheville AFB Blytheville, AR	T. H. Allen Plant Memphis, TN	65 (105)	16	1.60 (2.09)	375,363 (517,986)	99 (59)
Bolling AFB Washington, DC	Potomac River Plant Alexandria, VA	10 (16)	18	1.60 (2.09)	387,715 (535,032)	98 (58)
Brooks AFB San Antonio, TX	Big Brown Plant Fairfield, TX	220 (354)	41	.30 (.39)	192,179 (265,200)	56 (33)
Cannon AFB Clovis, NM	Cherokee Steam Plant Denver, CO	380 (612)	51	.03 (.04)	76,851 (106,051)	25 (15)
Carswell AFB Fort Worth, TX	Big Brown Plant Fairfield, TX	110 (117)	24	1.28 (1.67)	338,492 (467,106)	92 (55)
Castle AFB Merced, CA	Mohave Plant Laughlin, NV	375 (604)	54	.04 (.05)	50,977 (70,346)	16 (9)
Chanute AFB Rantoul, IL	E. D. Edwards Plant Bartonville, IL	90 (145)	19	1.47 (1.92)	361,308 (498,591)	97 (58)
Charleston AFB Charleston, SC	Wateree Plant Eastover, SC	85 (137)	29	.87 (1.13)	315,201 (434,965)	84 (50)
Columbus AFB Columbus, MS	Colbert Steam Plant Pride, AL	120 (193)	21	1.36 (1.78)	346,427 (478,056)	95 (56)
Craig AFB Selma, AL	E. C. Gaston Plant Wilsonville, AL	65 (105)	25	1.15 (1.50)	342,053 (472,020)	90 (54)
Davis-Monthan AFB Tuscon, AZ	Mohave Plant Laughlin, NV	300 (483)	57	0	13,012 (17,956)	4 (2)
Dobbins AFB Marietta, GA	McDonough-Atkinson Plant Smyrna, GA	20 (32)	21	1.36 (1.78)	372,877 (514,556)	95 (56)

Table A2 (Cont'd)

Data for Air Force Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Dover AFB Dover, DE	Eddystone Station Eddystone, PA	55 (89)	14	1.79 (2.34)	381,946 (527,071)	100 (59)
Duluth International Airport Duluth, MN	Allen S. King Plant Stillwater, MN	130 (209)	27	1.19 (1.56)	315,715 (435,674)	87 (52)
Dyess AFB Abilene, TX	Big Brown Plant Fairfield, TX	220 (354)	36	.59 (.77)	236,840 (326,830)	69 (41)
Edwards AFB Rosamond, CA	Mohave Plant Laughlin, NV	190 (306)	38	.56 (.73)	225,426 (311,079)	64 (38)
Eglin AFB Valpriso, FL	Christ Steam Plant Pensacola, FL	50 (80)	30	.89 (1.16)	315,115 (434,846)	82 (49)
Eglin Aux. Field #9 Mary Esther, FL	Christ Steam Plant Pensacola, FL	45 (72)	30	.90 (1.18)	316,155 (436,282)	82 (49)
Eielson AFB North Pole, AK	Centrailia Plant Centrailia, WA	2270 (3653)	133			
Ellington AFB Genoa, TX	Big Brown Plant Fairfield, TX	180 (290)	32	.79 (1.03)	274,686 (379,056)	78 (46)
Ellsworth AFB Box Elder, SD	Dave Johnson Plant Glenrock, WY	195 (314)	36	.61 (.80)	241,009 (332,583)	69 (41)
Elmendorf AFB Anchorage, AK	Centrailia Plant Centrailia, WA	2406 (3872)	140			
England AFB Alexandria, VA	Big Brown Plant Fairfield, TX	235 (378)	37	.56 (.73)	227,660 (314,162)	67 (40)
Ent AFB Colorado Springs, CO	Cherokee Steam Plant Denver, CO	72 (116)	17	1.74 (2.28)	369,573 (509,966)	98 (58)
Fairchild AFB Airway Heights, WA	Centrailia Plant Centrailia, WA	270 (435)	48	.10 (.13)	116,576 (160,870)	59 (35)
Fort Lee Petersburg, VA	Morgantown Plant Morgantown, MD	85 (137)	27	1.02 (1.33)	326,065 (449,957)	87 (52)
Francis Warren AFB Boulder, WY	Cherokee Steam Plant Denver, CO	110 (117)	20	1.54 (2.01)	352,020 (485,774)	96 (57)
General Mitchell Field Milwaukee, WI	Valley Plant Milwaukee, WI	10 (16)	20	1.45 (1.90)	379,620 (523,861)	96 (57)
George AFB Adelanto, CA	Mohave Plant Laughlin, NV	165 (266)	35	.68 (.89)	252,641 (348,635)	71 (42)

Table A2 (Cont'd)

Data for Air Force Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Goodfello AFB San Angelo, TX	Big Brown Plant Fairfield, TX	255 (410)	46	.13 (.17)	137,259 (189,412)	41 (24)
Grand Forks AFB Elmerado, ND	Hoot Lake Plant Fergus Falls, MN	130 (209)	29	.99 (1.29)	305,524 (421,611)	84 (50)
Pittsburg International Airport Corapolis, PA	F. R. Phillips Station South Heights, PA	25 (40)	23	1.34 (1.75)	363,503 (501,620)	93 (55)
Griffiss AFB Rome, NY	Merrimac Plant Concord, NH	200 (322)	71			
Grissom AFB Bunker Hill, IN	E. W. Stout Plant Indianapolis, IN	70 (113)	26	1.11 (1.45)	333,218 (459,828)	88 (52)
Gunter AFB Montgomery, AL	E. C. Gaston Plant Wilsonville, AL	65 (105)	24	1.25 (1.63)	349,670 (482,531)	92 (55)
Hamilton AFB Novato, CA	Mohave Plant Laughlin, NV	500 (805)	64			
Hancock Field North Syracuse, NY	Mercer Plant Hamilton Twp., NJ	225 (362)	74			
Hickman AFB Waialua, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Hill AFB Clearfield, UT	Navajo Plant Page, AZ	300 (483)	53	.04 (.05)	62,860 (86,744)	19 (11)
Holoman AFB Alamangordo, NM	Navajo Plant Page, AZ	400 (644)	67			
Homestead AFB Homestead, FL	Big Bend Plant Tampa, FL	225 (362)	51	.03 (.04)	85,764 (118,351)	25 (15)
Keesler AFB Biloxi, MS	Barry Power Plant Bucks, AL	80 (129)	25	1.22 (1.60)	338,430 (467,020)	92 (55)
Kelly AFB San Antonio, TX	Big Brown Plant Fairfield, TX	220 (354)	41	.30 (.39)	192,179 (265,200)	56 (33)
KI Sawyer AFB Gwinn, MI	J. P. Pulliam Plant Green Bay, WI	145 (233)	27	1.07 (1.40)	312,265 (430,914)	87 (52)
Kincheloe AFB Kincross, MI	J. C. Weadock & D. E. Karn Plant Essexville, MI	190 (306)	45	.16 (.21)	153,966 (212,467)	44 (26)
Kirtland AFB Albuquerque, NM	Navajo Plant Page, AZ	310 (499)	58	0		

Table A2 (Cont'd)

Data for Air Force Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/ Cement Cost Percentage	Cost Savings \$/cu yd (m^3)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Lackland AFB San Antonio, TX	Big Brown Plant Fairfield, TX	225 (362)	42	.29 (.38)	185,288 (255,690)	54 (32)
Langley AFB Hampton, VA	Morgantown Plant Morgantown, MD	105 (169)	29	.90 (1.18)	310,900 (429,030)	84 (50)
Laughlin AFB Del Rio, TX	Big Brown Plant Fairfield, TX	325 (523)	54	.04 (.05)	52,587 (72,568)	16 (9)
Laurence Hanscom AFB Bedford, MA	Merrimac Plant Concord, NH	60 (97)	58			
Little Rock AFB Jacksonville, AR	T. H. Allen Plant Memphis, TN	125 (201)	21	1.40 (1.83)	345,105 (476,231)	95 (56)
Loring AFB Limestone, ME	Merrimac Plant Concord, NH	340 (547)	87			
Los Angeles AFB Boron, CA	Mohave Plant Laughlin, NV	240 (386)	43	.26 (.34)	168,962 (233,161)	50 (30)
Lowry AFB Denver, CO	Cherokee Steam Plant Denver, CO	10 (16)	13	2.09 (2.73)	400,248 (552,327)	101 (60)
Luke AFB Litchfield Park, AZ	Mohave Plant Laughlin, NV	175 (282)	43	.23 (.30)	176,811 (243,922)	50 (30)
Macdill AFB Lynn Haven, FL	Gannon Plant Tampa, FL	15 (24)	27	1.05 (1.37)	342,165 (472,174)	87 (52)
Malstrom AFB Great Falls, MT	Dave Johnson Plant Glenrock, WY	415 (668)	53	.04 (.05)	244,344 (337,185)	19 (11)
March AFB Sunnymead, CA	Mohave Plant Laughlin, NV	175 (282)	36	.62 (.81)	224,344 (309,586)	69 (41)
Mather AFB Sacramento, CA	Mohave Plant Laughlin, NV	450 (724)	57	0	11,632 (16,052)	4 (2)
Maxwell AFB Montgomery, AL	F. C. Gaston Plant Wilsonville, AL	60 (97)	25	1.17 (1.53)	343,260 (473,685)	90 (53)
McChord AFB Tacoma, WA	Centrailia Plant Centrailia, WA	45 (72)	31	.97 (1.27)	308,400 (425,580)	80 (47)
McClellan AFB Sacramento, CA	Mohave Plant Laughlin, NV	465 (748)	58			
McConnel AFB Wichita, KS	LaCygne Station LaCygne, KS	150 (241)	34	.71 (.93)	266,773 (368,136)	74 (44)
McGuire AFB Wrightstown, NJ	Mercer Plant Hamilton Twp., NJ	25 (40)	59			

Table A2 (Cont'd)

Data for Air Force Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Dis-tance mi (km)	Fly Ash/ Cement Cost Per-centage	Cost Savings \$/cu yd (m^3)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Minn. St. Paul Airport Minneapolis, MN	Black Dog Plant Minneapolis, MN	15 (24)	19	1.74 (2.28)	382,439 (527,751)	97 (58)
Minot AFB Minot, ND	Leland Olds Plant Stanton, ND	80 (129)	35	.63 (.82)	267,499 (369,138)	71 (42)
Moody AFB Valdosta, GA	Harllee Branch Plant Eatonton, GA	175 (282)	38	.48 (.63)	227,651 (314,150)	64 (38)
Mountain Home AFB Mountain Home, ID	Centrailia Plant Centrailia, WA	450 (724)	72			
Myrtle Beach AFB Myrtle Beach, SC	Wateree Plant Eastover, SC	115 (185)	33	.68 (.89)	279,743 (386,034)	76 (45)
Nellis AFB Las Vegas, NV	Mohave Plant Laughlin, NV	95 (153)	31	.83 (1.09)	298,337 (411,693)	80 (47)
New Orleans NAS ANG New Orleans, LA	Barry Power Plant Bucks, AL	155 (249)	32	.79 (1.03)	279,516 (385,721)	78 (46)
Niagara Falls Airport Niagara Falls, NY	Eastlake Plant Eastlake, OH	190 (306)	41	.34 (.44)	196,216 (270,770)	56 (33)
Norton AFB North Sacramento, CA	Mohave Plant Laughlin, NV	175 (282)	36	.61 (.80)	244,344 (337,185)	69 (41)
Offutt AFB Bellevue, NB	North Omaha Station Omaha, NB	20 (32)	24	1.25 (1.63)	360,848 (497,956)	92 (55)
O'Hare Airport Park Ridge, IL	Crawford Plant Chicago, IL	20 (32)	23	1.25 (1.63)	364,779 (503,381)	93 (55)
Patrick AFB Cocoa Beach, FL	Big Bend Plant Tampa, FL	115 (185)	35	.62 (.81)	261,381 (360,696)	71 (42)
Pease AFB Newington, NH	Merrimac Plant Concord, NH	45 (72)	57.5	0	7,679 (10,597)	4 (2)
Peterson Field Colorado Springs, CO	Cherokee Steam Plant Denver, CO	72 (116)	17	1.74 (2.28)	369,573 (509,996)	98 (58)
Plattsburg AFB Plattsburg, NY	Merrimac Plant Concord, NH	60 (97)	58			
Pope AFB Spring Lake, NC	Roxboro Plant Roxboro, NC	90 (145)	27	1.00 (1.31)	324,915 (448,370)	87 (52)
Randolph AFB Universal City, TX	Big Brown Plant Fairfield, TX	205 (330)	40	.39 (.51)	205,445 (283,506)	59 (35)
Reese AFB Lubbock, TX	Big Brown Plant Fairfield, TX	370 (595)	52	.04 (.05)	57,043 (78,717)	19 (11)

Table A2 (Cont'd)

Data for Air Force Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings \$/cu yd (m^3)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Richards Gebaur AFB Belton, MO	Hawthorne Station Kansas City, MO	25 (40)	23	1.28 (1.67)	363,503 (501,620)	93 (55)
Rickenbacker AFB Lockbourne, OH	F. M. Tait Plant Dayton, OH	80 (129)	27	.98 (1.28)	327,215 (451,544)	87 (52)
Robbins AFB Warner Robbins, GA	Harllee Branch Plant Eatonton, GA	58 (93)	23	1.22 (1.60)	335,078 (462,395)	93 (55)
Scott AFB Shiloh, IL	Baldwin Plant Baldwin, IL	35 (56)	20	1.46 (1.91)	372,720 (514,339)	96 (57)
Selfridge AFB Mt. Clemens, MT	St. Clair Plant Belle River, MI	25 (40)	14	1.70 (2.22)	391,434 (540,164)	100 (59)
Semour Johnson Goldsboro, NC	Roxboro Plant Roxboro, NC	105 (169)	29	.90 (1.18)	310,900 (429,030)	84 (50)
Shaw AFB Sumpter, SC	Wateree Plant Eastover, SC	28 (45)	23	1.23 (1.61)	362,737 (500,563)	93 (55)
Shemya AFB Shemya, AK	Centrailia Plant Centrailia, WA	2736 (4403)	157			
Sheppard AFB Wichita Falls, TX	Big Brown Plant Fairfield, TX	210 (338)	37	.52 (.68)	231,685 (319,716)	67 (40)
Tinker AFB Midwest City, OK	LaCygne Station LaCygne, KS	250 (402)	46	.13 (.17)	137,748 (190,087)	41 (24)
Travis AFB Shafter, CA	Mohave Plant Laughlin, NV	470 (756)	59			
Tyndall AFB Springfield, FL	Christ Steam Plant Pensacola, FL	115 (185)	39	.41 (.54)	228,786 (315,716)	62 (37)
USAF Academy Monument, CO	Cherokee Steam Plant Denver, CO	50 (80)	16	1.86 (2.43)	379,882 (524,222)	99 (59)
Vance AFB Enid, OK	LaCygne Station LaCygne, KS	225 (362)	43	.23 (.30)	170,773 (235,660)	50 (30)
Vanderburg AFB Lompoc, CA	Mohave Plant Laughlin, NV	350 (563)	53	.04 (.05)	60,848 (83,968)	19 (11)
Webb AFB Big Spring, TX	Big Brown Plant Fairfield, TX	320 (515)	53	.04 (.05)	62,055 (85,633)	19 (11)
Westover AFB Chicopee, MA	Merrimac Plant Concord, NH	95 (153)	67			
Wheeler AFB Waipahu, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			

Table A2 (Cont'd)

Data for Air Force Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings \$/cu yd (m³)	Total Energy Savings Btu/cu yd (kJ/m³)	Cement Savings lb/cu yd (kg/m³)
Whiteman AFB Knob Noster, MO	Montrose Station Clinton, MO	35 (56)	24	1.24 (1.62)	357,122 (492,814)	92 (55)
Williams AFB Chandler, AZ	Mohave Plant Laughlin, AZ	220 (354)	48	1.24 (1.62)	120,601 (166,425)	35 (21)
Willow Grove Air Reserve Facility Hatboro, PA	Eddystone Station Eddystone, PA	48 (77)	14	1.82 (2.38)	384,160 (530,126)	100 (59)
Wright Patterson AFB Fairborn, OH	F. M. Tait Plant Dayton, OH	20 (32)	22	1.25 (1.63)	368,782 (508,905)	94 (56)
Wurtsmith AFB Osconda, MI	J. C. Weadock & D. E. Karn Plant Essexville, MI	75 (121)	30	.81 (1.06)	309,911 (427,665)	82 (49)
Youngstown Municipal Airport Vienna, OH	F. R. Phillips Station South Heights, PA	50 (80)	22	1.44 (1.88)	360,916 (498,050)	94 (56)

Table A3

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/ Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Academy Annapolis, MD	Chalk Point Aquasco, MD	28 (45)	24	1.14 (1.49)	358,861 (495,214)	92 (55)
Aerospace & Regional Med. Center Pensacola, FL	Christ Steam Plant Pensacola, FL	20 (32)	26	1.11 (1.45)	345,005 (476,093)	88 (52)
Air Development Center Warminster, PA	Mercer Plant Hamilton Twp., NJ	30 (48)	60			
Air Engineering Center Lakehurst, NJ	Mercer Plant Hamilton Twp., NJ	30 (48)	60			
Air Facility El Centro, CA	Mohave Plant Laughlin, NV	180 (290)	43	.23 (.30)	176,207 (243,159)	50 (30)
Air Propulsion Test Center Trenton, NJ	Mercer Plant Hamilton Twp., NJ	15 (24)	60			
Air Rework Facility Alameda, CA	Mohave Plant Laughlin, NV	500 (805)	64			
Air Rework Facility Cherry Point, NC	Roxboro Plant Roxboro, NC	165 (266)	36	.56 (.73)	246,011 (339,486)	69 (41)
Air Rework Facility Jacksonville, FL	Gannon Plant Tampa, FL	172 (277)	46	.13 (.17)	145,372 (200,608)	41 (24)
Air Rework Facility Norfolk, VA	Morgantown Plant Morgantown, MD	115 (185)	30	.86 (1.12)	301,585 (416,176)	82 (49)
Air Rework Facility North Island, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Air Rework Facility Pensacola, FL	Christ Steam Plant Pensacola, FL	20 (32)	26	.79 (1.03)	345,005 (476,093)	88 (52)
Air Station Alameda, CA	Mohave Plant Laughlin, NV	500 (804)	64			
Air Station, Atlanta Marietta, GA	McDonough-Atkinson Plant Smyrna, GA	10 (16)	19	1.46 (1.91)	383,848 (529,685)	97 (58)
Air Station Barbers Point, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Air Station Brunswick, ME	Merrimac Plant Concord, NH	100 (161)	62			
Air Station, Cecil Field Jacksonville, FL	Big Bend Plant Tampa, FL	162 (261)	45	.15 (.20)	156,928 (216,554)	44 (26)
Air Station, Chase Field Beeville, TX	Big Brown Plant Fairfield, TX	265 (426)	47	.12 (.16)	126,764 (174,929)	38 (23)

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Air Station Corpus Christi, TX	Big Brown Plant Fairfield, TX	300 (483)	51	.03 (.04)	81,451 (112,399)	25 (15)
Air Station Dallas, TX	Big Brown Plant Fairfield, TX	85 (137)	21	1.44 (1.88)	355,685 (490,831)	95 (56)
Air Station Fallon, NV	Mohave Plant Laughlin, NV	390 (628)	55	.04 (.05)	38,310 (52,866)	12 (7)
Air Station Glenview, IL	Fisk Power Plant Chicago, IL	25 (40)	23	1.24 (1.62)	363,503 (501,620)	93 (55)
Air Station Jacksonville, FL	Gannon Power Plant Tampa, FL	172 (277)	46	.13 (.17)	145,372 (200,608)	41 (24)
Air Station Key West, FL	Big Bend Plant Tampa, FL	260 (418)	55	.03 (.04)	41,300 (56,992)	12 (7)
Air Station Kingsville, TX	Big Brown Plant Fairfield, TX	320 (515)	53	.04 (.05)	62,055 (85,633)	19 (11)
Air Station Lakehurst, NJ	Mercer Plant Hamilton Twp., NJ	30 (48)	60			
Air Station Lemoore, CA	Mohave Plant Laughlin, NV	325 (523)	53	.04 (.05)	61,854 (85,356)	19 (11)
Air Station Los Alamitos, CA	Mohave Plant Laughlin, NV	240 (386)	43	.26 (.34)	168,962 (233,161)	50 (30)
Air Station Memphis, TN	T. H. Allen Plant Memphis, TN	23 (37)	13	1.95 (2.55)	396,092 (546,592)	101 (60)
Air Station Meridan, MS	Barry Power Plant Bucks, AL	118 (190)	30	.87 (1.14)	300,960 (415,313)	82 (49)
Air Station, Miramar San Diego, CA	Mohave Plant Laughlin, NV	225 (362)	48	.10 (.13)	120,199 (165,870)	35 (21)
Air Station, Moffett Field Mountain View, CA	Mohave Plant Laughlin, NV	470 (756)	62			
Air Station New Orleans, LA	Barry Power Plant Bucks, AL	155 (249)	32	.79 (1.03)	279,516 (385,721)	78 (46)
Air Station Norfolk, VA	Morgantown Plant Morgantown, MD	115 (185)	30	.86 (1.12)	301,585 (416,176)	82 (49)
Air Station, North Island San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Air Station, Oceana Virginia Beach, VA	Morgantwon Plant Morgantown, MD	130 (209)	32	.77 (1.01)	284,346 (392,386)	78 (46)

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/ Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Air Station Pensacola, FL	Christ Steam Plant Pensacola, FL	20 (32)	26	1.12 (1.46)	345,005 (476,093)	88 (52)
Air Station Point Mugu, CA	Mohave Plant Laughlin, NV	300 (483)	48	.11 (.14)	114,161 (157,538)	35 (21)
Air Station, Saufley Field Pensacola, FL	Christ Steam Plant Pensacola, FL	12 (19)	26	1.14 (1.49)	346,891 (478,696)	88 (52)
Air Station South Weymouth, MA	Merrimac Plant Concord, NH	85 (137)	60			
Air Station, Washington, DC Camp Springs, MD	Chalk Point Aquasco, MD	10 (16)	21	1.39 (1.82)	375,522 (518,206)	95 (56)
Air Station, Whidbey Island Oak Harbor, WA	Centrailia Plant Centrailia, WA	120 (193)	35	.71 (.93)	260,507 (359,490)	80 (47)
Air Station, Whiting Field Milton, FL	Christ Steam Plant Pensacola, FL	22 (35)	26	1.12 (1.46)	344,534 (475,444)	88 (52)
Air Station Willow Grove, PA	Eddystone Station Eddystone, PA	30 (48)	13	1.93 (2.52)	393,854 (543,503)	101 (60)
Air Test Center Patuxent River, MD	Morgantown Plant Morgantown, MD	35 (56)	23	1.25 (1.63)	360,950 (498,097)	93 (55)
Ammo Depot Crane, IN	Petersburg Plant Petersburg, IN	43 (69)	24	1.26 (1.65)	355,135 (490,072)	92 (55)
Ammo Depot Hawthorne, NV	Mohave Plant Laughlin, NV	290 (467)	47	.13 (.17)	124,551 (171,876)	38 (23)
Ammo Depot McAlester, OK	Big Brown Plant Fairfield, TX	210 (338)	37	.52 (.68)	231,685 (319,716)	67 (40)
Amphibious Base San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Amphibious Base, Little Creek Norfolk, VA	Morgantown Plant Morgantown, MD	120 (193)	31	.61 (.80)	293,306 (404,751)	80 (47)
Avionics Facility Indianapolis, IN	E. W. Stout Plant Indianapolis, IN	5 (8)	21	1.44 (1.88)	376,845 (520,031)	95 (56)
Camp H. M. Smith Halawa Heights, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Coastal System Lab Panama City, FL	Christ Steam Plant Pensacola, FL	95 (153)	37	.50 (.65)	250,200 (345,266)	67 (40)
Communications Station, Clam Lagoon Adak, AK	Centrailia Plant Centrailia, WA	2556 (4113)	148			

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/ Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Communications Station Honolulu, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Communications Station Key West, FL	Gannon Power Plant Tampa, FL	260 (418)	55	.03 (.04)	41,300 (56,992)	12 (7)
Communications Station Newport, RI	Merrimac Plant Concord, NH	130 (209)	64			
Communications Station Norfolk, VA	Morgantown Plant Morgantown, MD	115 (185)	30	.86 (1.12)	301,585 (416,176)	82 (49)
Communications Station San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Communications Station, San Francisco Stockton, CA	Mohave Plant Laughlin, NV	430 (692)	57.7	0	3,530 (4,871)	1 (.6)
Communications Station, Washington Cheltenham, MD	Potomac River Plant Alexandria, VA	20 (32)	19	1.52 (1.99)	381,030 (525,807)	97 (58)
Construction Battalion Center Davisville, RI	Merrimac Plant Concord, NH	125 (201)	64			
Construction Battalion Center Gulfport, MS	Barry Power Plant Bucks, AL	88 (142)	25	1.19 (1.56)	336,498 (464,354)	90 (53)
Construction Battalion Center Port Hueneme, CA	Mohave Plant Laughlin, NV	285 (459)	46	.13 (.17)	134,326 (185,365)	41 (24)
Damage Control Training Center Philadelphia, PA	Eddystone Station Eddystone, PA	10 (16)	11	2.07 (2.71)	404,598 (558,329)	102 (61)
Electronics Lab Center San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Facility, Cape Hatteras Buxton, NC	Roxboro Plant Roxboro, NC	215 (346)	42	.29 (.38)	186,553 (257,436)	54 (32)
Facility Pacific Beach, WA	Centrailia Plant Centrailia, WA	75 (121)	32	.97 (1.27)	294,972 (407,050)	80 (47)
Fleet Antisubmarine Training San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Fleet, Ballistic Missile Center Charleston, SC	Wateree Plant Eastover, SC	90 (145)	30	.[illegible]2 (1.09)	216,789 (299,160)	82 (49)
Fleet Operations Control Center Kunia, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Fleet Training Center Mayport, FL	Big Bend Plant Tampa, FL	185 (298)	48	.09 (.12)	123,419 (170,313)	35 (21)

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Fleet Training Center San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Fuel Depot Jacksonville, FL	Gannon Power Plant Tampa, FL	180 (290)	48	.10 (.13)	123,821 (170,868)	35 (21)
Hospital Annapolis, MD	Chalk Point Aquasco, MD	28 (45)	24	1.14 (1.49)	358,861 (495,214)	92 (55)
Hospital Beaufort, SC	Wateree Plant Eastover, SC	105 (169)	31	.75 (.98)	296,325 (408,917)	80 (47)
Hospital Cherry Point, NC	Roxboro Plant Roxboro, NC	165 (266)	36	.55 (.72)	246,011 (339,486)	69 (41)
Hospital Corpus Christi, TX	Big Brown Plant Fairfield, TX	300 (483)	51	.03 (.04)	81,451 (112,399)	25 (15)
Hospital Key West, FL	Big Bend Plant Tampa, FL	260 (418)	56	.04 (.05)	27,059 (37,340)	8
Hospital Lemoore, CA	Mohave Plant Laughlin, NV	325 (523)	50	.06 (.08)	93,205 (128,619)	29 (17)
Hospital Memphis, TN	T. H. Allen Plant Memphis, TN	23 (37)	13	1.95 (2.55)	396,092 (546,592)	101 (60)
Hospital Oak Harbor, WA	Centrailia Plant Centrailia, WA	120 (193)	35	.70 (.92)	260,507 (359,490)	80 (47)
Hospital Orlando, FL	Big Bend Plant Tampa, FL	82 (132)	32	.78 (1.02)	293,620 (405,184)	78 (46)
Hospital Patuxent River, MD	Morgantown Plant Morgantown, MD	35 (56)	23	1.24 (1.62)	360,950 (498,097)	93 (55)
Hospital Port Hueneme, CA	Mohave Plant Laughlin, NV	285 (459)	46	.13 (.17)	134,326 (185,365)	41 (24)
Hospital Quantico, VA	Potomac River Plant Alexandria, VA	28 (45)	19	1.50 (1.96)	378,776 (522,696)	97 (58)
Magazine Lualualei, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Marine Barracks Norfolk, VA	Morgantown Plant Morgantown, MD	115 (185)	30	.86 (1.12)	301,585 (416,176)	82 (49)
Marine Barracks Pearl Harbor, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Marine Corps Air Station Beaufort, SC	Wateree Plant Eastover, SC	105 (169)	31	.75 (.98)	296,325 (408,917)	80 (47)

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd (m³)	Total Energy Savings Btu/cu yd (kJ/m³)	Cement Savings lb/cu yd (kg/m³)
Marine Corps Air Station Cherry Point, NC	Roxboro Plant Roxboro, NC	165 (266)	36	.55 (.72)	246,011 (339,486)	69 (41)
Marine Corps Air Station, El Toro Santa Anna, CA	Mohave Plant Laughlin, NV	210 (338)	40	.45 (.59)	204,755 (282,554)	59 (35)
Marine Corps Air Station, Kaneohe Bay Oahu, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Marine Corps Air Station Quantico, VA	Potomac River Plant Alexandria, VA	28 (45)	19	1.50 (1.96)	378,776 (522,696)	97 (58)
Marine Corps Air Station Yuma, AZ	Mohave Plant Laughlin, NV	175 (282)	42	.29 (.38)	191,613 (264,418)	54 (32)
Marine Corps Air Station, New River Jacksonville, NC	Roxboro Plant Roxboro, NC	165 (266)	36	.55 (.72)	246,011 (339,486)	69 (41)
Marine Corps Air Station Santa Ana, CA	Mohave Plant Laughlin, NV	200 (322)	39	.50 (.65)	216,372 (298,585)	62 (37)
Marine Corps Base Camp Lejeune, NC	Roxboro Plant Roxboro, NC	165 (266)	36	.55 (.72)	246,011 (339,486)	69 (41)
Marine Corps Base Camp Pendleton, CA	Mohave Plant Laughlin, NV	220 (354)	47	.12 (.16)	130,749 (180,429)	38 (23)
Marine Corps Base Twentynine Palms, CA	Mohave Plant Laughlin, NV	115 (185)	35	.59 (.77)	261,381 (360,696)	71 (42)
Marine Corps. Devel. & Ed. Command Quantico, VA	Potomac River Plant Alexandria, VA	28 (45)	19	1.50 (1.96)	378,776 (522,696)	97 (58)
Marine Corps Hdqtrs. Battalion Washington, DC	Dickerson Plant Dickerson, MD	15 (24)	22	1.30 (1.70)	370,093 (510,714)	94 (56)
Marine Corps Recruit Depot Parris Island, SC	Wateree Plant Eastover, SC	115 (185)	33	.68 (.89)	279,743 (386,034)	76 (45)
Marine Corps Recruit Depot San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Marine Corps Supply Activity Philadelphia, PA	Eddystone Station Eddystone, PA	25 (40)	12	1.97 (2.58)	399,522 (551,325)	102 (61)
Marine Corps Supply Center Albany, GA	Harllee Branch Plant Eatonton, GA	145 (233)	29	.96 (1.26)	302,298 (417,159)	84 (50)
Marine Corps Supply Center Barstow, CA	Mohave Plant Laughlin, NV	142 (229)	33	.80 (1.05)	274,651 (379,008)	76 (45)
National Naval Medical Center Bethesda, MD	Dickerson Plant Dickerson, MD	10 (16)	21	1.39 (1.82)	375,522 (518,206)	95 (56)

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/ Cement Cost Percentage	Cost Savings $/cu yd (m³)	Total Energy Savings Btu/cu yd (kJ/m³)	Cement Savings lb/cu yd (kg/m³)
Naval Observatory Washington, DC	Dickerson Plant Dickerson, MD	15 (24)	22	1.30 (1.70)	370,093 (510,714)	94 (56)
Naval Observatory Station Flagstaff, AZ	Navajo Plant Page, AZ	135 (217)	38	.49 (.64)	233,585 (322,338)	64 (38)
Ordnance Missile Test Facility White Sands, NM	Navajo Plant Page, AZ	440 (708)	70			
Ordnance Station Indian Head, MD	Potomac River Plant Alexandria, VA	22 (35)	19	1.50 (1.96)	380,467 (525,030)	97 (58)
Ordnance Station Louisville, KY	Cane Run Plant Louisville, KY	20 (32)	18	1.45 (1.90)	384,840 (531,064)	98 (58)
Pacific Missile Range Point Mugu, CA	Mohave Plant Laughlin, NV	275 (443)	46	.15 (.20)	135,304 (186,714)	41 (24)
Photographic Center Washington, DC	Potomac River Plant Alexandria, VA	10 (16)	18	1.60 (2.09)	387,715 (535,032)	98 (58)
Polaris Missile Facility, Atlantic Charleston, SC	Wateree Plant Eastover, SC	95 (153)	30	.82 (1.07)	305,748 (421,920)	82 (49)
Post Graduate Center Monterey, CA	Mohave Plant Laughlin, NV	405 (652)	60			
Public Works Center Great Lakes, IL	Waukegan #1 Plant Waukegan, IL	10 (16)	22	1.31 (1.71)	371,404 (512,523)	94 (56)
Public Works Center Norfolk, VA	Morgantown Plant Morgantown, MD	115 (185)	30	.86 (1.12)	301,585 (416,176)	82 (49)
Public Works Center Pearl Harbor, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Public Works Center Pensacola, FL	Christ Steam Plant Pensacola, FL	20 (32)	26	1.12 (1.46)	345,005 (476,093)	88 (52)
Public Works Center San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Radio Station Cutler, ME	Merrimac Plant Concord, NH	240 (386)	77			
Radio Station Jim Creek, WA	Centrailia Plant Centrailia, WA	125 (201)	36	.68 (.89)	252,681 (348,690)	80 (47)
Radio Station Sugar Grove, WV	Albright Station Albright, WV	75 (121)	18	1.47 (1.92)	369,028 (509,244)	98 (58)
Regional Medical Center Bremerton, WA	Centrailia Plant Centrailia, WA	65 (105)	31	.97 (1.27)	304,375 (420,026)	80 (47)

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Regional Medical Center Camp Lejeune, NC	Roxboro Plant Roxboro, NC	165 (266)	36	.55 (.72)	246,011 (339,486)	69 (41)
Regional Medical Center Camp Pendleton, CA	Mohave Plant Laughlin, NV	205 (330)	46	.14 (.18)	142,146 (196,156)	41 (24)
Regional Medical Center Charleston, SC	Wateree Plant Eastover, SC	100 (161)	31	.77 (1.01)	297,331 (410,305)	80 (47)
Regional Medical Center Great Lakes, IL	Waukegan #1 Plant Waukegan, IL	10 (16)	22	1.31 (1.71)	371,404 (512,523)	94 (56)
Regional Medical Center Long Beach, CA	Mohave Plant Laughlin, NV	240 (386)	43	.26 (.34)	168,962 (233,161)	50 (30)
Regional Medical Center Jacksonville, FL	Big Bend Plant Tampa, FL	172 (277)	46	.13 (.17)	145,372 (200,608)	41 (24)
Regional Medical Center Newport, RI	Merrimac Plant Concord, NH	135 (217)	65			
Regional Medical Center Oakland, CA	Mohave Plant Laughlin, NV	500 (805)	64			
Regional Medical Center Philadelphia, PA	Eddystone Plant Eddystone, PA	10 (16)	11	2.07 (2.71)	404,598 (558,329)	102 (61)
Regional Medical Center Portsmouth, VA	Morgantown Plant Morgantown, MD	120 (193)	31	.81 (1.06)	293,306 (404,751)	80 (47)
Regional Medical Center Washington, DC	Potomac River Plant Alexandria, VA	10 (16)	18	1.60 (2.09)	387,715 (535,032)	98 (58)
Schools Command, Treasure Island San Francisco, CA	Mohave Plant Laughlin, NV	510 (821)	65			
Security Group Activity Skaggs Island, CA	Mohave Plant Laughlin, NV	500 (805)	64			
Security Group Activity Winter Harbor, ME	Merrimac Plant Concord, NH	205 (330)	74			
Security Station Washington, DC	Dickerson Plant Dickerson, MD	10 (16)	21	1.39 (1.82)	275,522 (380,210)	95 (56)
Ship Research & Development Center Bethesda, MD	Dickerson Plant Dickerson, MD	5 (8)	21	1.39 (1.82)	376,845 (520,031)	95 (56)
Ship Parts Control Center Mechanicsburg, PA	Dickerson Plant Dickerson, MD	90 (145)	30	.82 (1.07)	306,789 (423,357)	82 (49)
Shipyard Charleston, SC	Wateree Plant Eastover, SC	100 (161)	31	.77 (1.01)	297,331 (410,305)	80 (47)

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/ Cement Cost Percentage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Shipyard Long Beach, CA	Mohave Plant Laughlin, NV	240 (386)	43	.26 (.34)	156,542 (216,022)	50 (30)
Shipyard Mare Island, CA	Mohave Plant Laughlin, NV	490 (789)	64			
Shipyard, Norfolk Portsmouth, VA	Morgantown Plant Morgantown, MD	120 (193)	31	.82 (1.07)	293,306 (404,751)	80 (47)
Shipyard Pearl Harbor, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Shipyard Philadelphia, PA	Eddystone Station Eddystone, PA	10 (16)	11	2.07 (2.71)	404,598 (558,329)	102 (61)
Shipyard Portsmouth, NH	Merrimac Plant Concord, NH	45 (72)	57.5	0	7,679 (10,597)	2 (1)
Shipyard, Puget Sound Bremerton, WA	Centrailia Plant Centrailia, WA	65 (105)	31	.97 (1.27)	304,375 (420,026)	80 (47)
Naval Station Adak, AK	Centrailia Plant Centrailia, WA	2636 (4242)	152			
Naval Station Annapolis, MD	Chalk Point Plant Aquasco, MD	28 (45)	24	1.14 (1.49)	358,861 (495,214)	92 (55)
Naval Station Charleston, SC	Wateree Plant Eastover, SC	100 (161)	31	.77 (1.01)	297,331 (410,305)	80 (47)
Naval Station Mayport, FL	Big Bend Plant Tampa, FL	185 (298)	48	.09 (.12)	123,419 (170,313)	35 (21)
Naval Station Norfolk, VA	Morgantown Plant Morgantown, MD	115 (185)	30	.86 (1.12)	301,585 (416,176)	82 (49)
Naval Station Pearl Harbor, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Naval Station San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Naval Station, Treasure Island San Francisco, CA	Mohave Plant Laughlin, NV	510 (821)	65			
Submarine Base New London, CT	Merrimac Plant Concord, NH	140 (225)	72			
Submarine Base Pearl Harbor, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Supply Index, Cheatham Williamsburg, VA	Morgantown Plant Morgantown, MD	82 (132)	27	1.02 (1.33)	326,755 (450,909)	87 (52)

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Dis-tance mi (km)	Fly Ash/Cement Cost Per-centage	Cost Savings $/cu yd ($m^3$)	Total Energy Savings Btu/cu yd (kJ/m^3)	Cement Savings lb/cu yd (kg/m^3)
Supply Center Charleston, SC	Wateree Plant Eastover, SC	100 (161)	31	.77 (1.01)	297,331 (410,305)	80 (47)
Supply Center Norfolk, VA	Morgantown Plant Morgantown, MD	115 (185)	30	.86 (1.12)	301,585 (416,176)	82 (49)
Supply Center Oakland, CA	Mohave Plant Laughlin, NV	500 (805)	64			
Supply Center Pearl Harbor, HI	Mohave Plant Laughlin, NV	2591 (4170)	204			
Supply Center, Puget Sound Bremerton, WA	Centrailia Plant Centrailia, WA	65 (105)	31	.97 (1.27)	304,375 (420,026)	80 (47)
Supply Center San Diego, CA	Mohave Plant Laughlin, CA	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Supply Corps School Athens, GA	Harllee Branch Plant Eatonton, GA	48 (77)	23	1.26 (1.65)	357,631 (493,517)	93 (55)
Support Activity Brooklyn, NY	Mercer Plant Hamilton Twp., NJ	55 (89)	61			
Support Activity Long Beach, CA	Mohave Plant Laughlin, NV	240 (386)	43	.26 (.34)	168,962 (233,161)	50 (30)
Support Activity Mare Island, CA	Mohave Plant Laughlin, NV	490 (789)	64			
Support Activity New Orleans, LA	Barry Power Plant Bucks, AL	148 (238)	32	.82 (1.07)	280,868 (387,587)	78 (46)
Support Activity Philadelphia, PA	Eddystone Station Eddystone, PA	10 (16)	11	2.07 (2.71)	404,598 (558,329)	102 (61)
Support Activity Seattle, WA	Centrailia Plant Centrailia, WA	65 (105)	31	.97 (1.27)	304,375 (420,026)	80 (47)
Technical Training Center Meridian, MS	Barry Power Plant Bucks, AL	118 (190)	30	.87 (1.14)	300,960 (415,313)	82 (49)
Technical Training Center Pensacola, FL	Christ Steam Plant Pensacola, FL	18 (29)	26	1.13 (1.48)	345,477 (476,745)	88 (52)
Torpedo Station Keyport, WA	Centrailia Plant Centrailia, WA	75 (121)	31	.97 (1.27)	302,362 (417,248)	80 (47)
Training Center Bainbridge, MD	Eddystone Plant Eddystone, PA	48 (77)	15	1.70 (2.22)	384,294 (530,311)	100 (59)

Table A3 (Cont'd)

Data for Naval Installations

Military Installation	Nearest Major Source of Suitable Fly Ash	Distance mi (km)	Fly Ash/Cement Cost Percentage	Cost Savings $/cu yd (m³)	Total Energy Savings Btu/cu yd (kJ/m³)	Cement Savings lb/cu yd (kg/m³)
Training Center Great Lakes, IL	Waukegan #1 Plant Waukegan, IL	10 (16)	22	1.31 (1.71)	371,404 (512,523)	94 (56)
Training Center Orlando, FL	Big Bend Plant Tampa, FL	82 (132)	32	.78 (1.02)	293,620 (405,184)	78 (46)
Training Center San Diego, CA	Mohave Plant Laughlin, NV	235 (378)	49	.07 (.09)	109,132 (150,598)	32 (19)
Underwater Systems Center Newport, RI	Merrimac Plant Concord, NH	135 (217)	66			
Weapons Center China Lake, CA	Mohave Plant Laughlin, NV	365 (587)	53	.03 (.04)	60,244 (83,134)	19 (11)
Weapons Lab Dahlgren, VA	Morgantown Plant Morgantown, MD	5 (8)	21	1.39 (1.82)	376,845 (520,031)	95 (56)
Weapons Station Charleston, SC	Wateree Plant Eastover, SC	95 (153)	30	.82 (1.07)	305,748 (421,920)	82 (49)
Weapons Station Concord, CA	Mohave Plant Laughlin, NV	500 (805)	64			
Weapons Station Earle, NJ	Mercer Plant Hamilton Twp., NJ	34 (55)	59			
Weapons Station Seal Branch, CA	Mohave Plant Laughlin, NV	210 (338)	40	.45 (.59)	204,755 (282,554)	59 (35)
Weapons Station Yorktown, VA	Morgantown Plant Morgantown, MD	90 (145)	28	.98 (1.28)	317,533 (438,183)	85 (50)

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